AD-A055 992

AD

AD-E400 159

TECHNICAL REPORT ARLCD-TR-77080

THREE-BEACON PROJECTILE GUIDANCE STUDY

JOHN R. MASLY
LCWSL, ARRADCOM

DR. RICHARD A. HADDAD
POLYTECHNIC INSTITUTE OF BROOKLYN

MARCH 1978

U.S. ARMY ARRADCOM

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report ARLCD-TR-77080	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THREE-BEACON PROJECTILE GUIDANCE STUDY		5. TYPE OF REPORT & PERIOD COVERED Final 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John R. Masly Dr. Richard A. Haddad		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Commander, ARRADCOM ATTN: DRDAR-LCN-F Dover, NJ 07801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Commander, ARRADCOM ATTN: DRDAR-TSS Dover, NJ 07801		12. REPORT DATE March 1978 13. NUMBER OF PAGES 128
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Commander, ARRADCOM ATTN: DRDAR-LCN-F Dover, NJ 07801		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Projectile guidance
Beacon guidance system
Computer simulation
Trajectories

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The feasibility of employing an array of three ground-based beacons operating as distance measuring equipment (DME) transponders to accurately guide a projectile to a target is explored. For simplification of the problem, the projectile is assumed to be a point mass, with only drag, gravity and control forces acting on it. A projected planar guidance law is adopted for the projectile and it is assumed that the guidance law can be implemented exactly. Estimates of targeting errors are obtained by computer simulation, as functions of beacon-to-beacon spacing, guidance

20. Abstract (continued)

cut-off altitude, terminal velocity, and beacon location errors. Results of a statistical analysis on the computer simulations indicate that the major parameters affecting the desired accuracy at the target are beacon-to-beacon spacing and beacon-target geometry.

INTRODUCTION

This report presents the initial study on a guidance system for improved accuracy projectiles that employs three, pre-emplaced beacons, as shown in figure 1.

Three beacons, B_1, B_2, and B_3, are emplaced by some means in the vicinity of a fixed target, T. The locations of the target and the beacons are assumed known 'a priori', within specified statistical errors, from intelligence sources. A transponder at each beacon site transmits signals to a receiver in the projectile, where a micro-processor calculates the ranges, R_1, R_2, and R_3, from the projectile to the beacons, B_1, B_2, and B_3, respectively.

Utilizing the a priori beacon, target location data and the measured ranges, the on-board micro-processor calculates the instantaneous projectile position and the projectile-to-target vector. This vector is then utilized as the steering signal input to a navigator which generates the control forces necessary to guide the projectile to the target.

The objectives of this study are:

1. Determine the feasibility of the three-beacon guidance system to locate, precisely, the coordinates of the projectile relative to an inertial reference system, given the beacon and target locations and the projectile-to-beacon ranges.

2. Determine the needed beacon and target location accuracies needed to achieve a specified circular error probability (CEP) at impact.

3. Determine the feasibility and applicability of using the projected planar guidance system, as utilized by Sandia Corporation (ref. 1), for solving this problem.

GEOMETRY OF THE THREE-BEACON SYSTEM

The three beacons, B_1, B_2, and B_3, are assumed to be emplaced at some nominally known locations with respect to an inertial reference frame (x, y, z) as shown in figure 2.

A beacon-based coordinate system (x', y', z') will be erected with the origin, O', at the location of beacon B_1, the x'-axis along the line from B_1 to B_2, all three beacons in the x'-y' plane, and the z'-axis orthogonal to the x'-y' plane.

In order to assign identities to the pre-emplaced beacons so that the geometry shown in figure 2 is accurate, the following methodology is employed:

1. Beacon B_1 is chosen as that beacon closest in distance to the origin of the inertial reference frame.

2. A tentative choice for B_2 is made from the remaining two beacons and the vector cross product $\overrightarrow{B_1 B_2} \times \overrightarrow{B_1 B_3}$ is determined and then normalized to determine the unit vector, $\bar{k}'$, in the z' direction.

3. This process is repeated after interchanging the identities of beacons B_2 and B_3.

4. The scalar product $\bar{k} \cdot \bar{k}'$ is then calculated for each $\bar{k}'$.

5. Beacon B_2 is then taken as that choice of B_2 that results in a positive scalar product, $\bar{k} \cdot \bar{k}'$, with B_3 as the remaining beacon.

This identity assignment will be accomplished at the firing site, or at some ground station, once the beacon locations have been determined.

With respect to the inertial reference frame, the assumed coordinates of the beacons are:

$$\overrightarrow{R_{OB_1}} = \bar{i}\ a_1 + \bar{j}\ b_1 + \bar{k}\, c_1 \tag{1}$$
$$\overrightarrow{R_{OB_2}} = \bar{i}\ a_2 + \bar{j}\ b_2 + \bar{k}\, c_2$$
$$\overrightarrow{R_{OB_3}} = \bar{i}\ a_3 + \bar{j}\ b_3 + \bar{k}\, c_3$$

The equation of a plane passing through all three beacons is:

$$\begin{vmatrix} (x-a_1) & (y-b_1) & (z-c_1) \\ (a_2-a_1) & (b_2-b_1) & (c_2-c_1) \\ (a_3-a_1) & (b_3-b_1) & (c_3-c_1) \end{vmatrix} = 0 \tag{2}$$

Upon expanding equation (2), we have

$$A\ (x-a_1) + B\ (y-b_1) + C\ (z-c_1) = 0 \tag{3}$$

or

$$Ax + By + Cz = D \tag{4}$$

where

$$A = (b_2 - b_1)\ (c_3 - c_1) - (b_3 - b_1)\ (c_2 - c_1) \tag{5}$$

$$B = (a_3 - a_1)\ (c_2 - c_1) - (a_2 - a_1)\ (c_3 - c_1)$$

$$C = (a_2 - a_1)\ (b_3 - b_1) - (a_3 - a_1)\ (b_2 - b_1)$$

$$D = Aa_1 + Bb_1 + Cc_1$$

We can normalize equation (4) to obtain the equation of the plane through B_1, B_2, B_3 as,

$$x \cos \alpha_3 + y \cos \beta_3 + z \cos \gamma_3 = p \tag{6}$$

where

$$\cos \alpha_3 = A/(A^2 + B^2 + C^2)^{\frac{1}{2}} \tag{7}$$

$$\cos \beta_3 = B/(A^2 + B^2 + C^2)^{\frac{1}{2}}$$

$$\cos \gamma_3 = C/(A^2 + B^2 + C^2)^{\frac{1}{2}}$$

$$p = D/(A^2 + B^2 + C^2)^{\frac{1}{2}}$$

The three cosines are the direction cosines of the plane and p is the perpendicular distance from the origin of the inertial reference frame to the plane. Thus, a unit vector normal to this plane is

$$\bar{k}' = (\cos \alpha_3)\ \bar{i} + (\cos \beta_3)\ \bar{j} + (\cos \gamma_3)\ \bar{k} \tag{8}$$

The unit vector $\bar{i}'$ along $\overrightarrow{B_1 B_2}$ is obtained as follows:

$$\overrightarrow{B_1B_2} = \overrightarrow{OB_2} - \overrightarrow{OB_1} = \bar{i}\ (a_2 - a_1) + \bar{j}\ (b_2 - b_1) + \bar{k}\ (c_2 - c_1) \tag{9}$$

Normalizing this we obtain

$$\bar{i}' = (\cos \alpha_1)\ \bar{i} + (\cos \beta_1)\ \bar{j} + (\cos \gamma_1)\ \bar{k} \tag{10}$$

where

$$\cos \alpha_1 = (a_2 - a_1)/\left[(a_2 - a_1)^2 + (b_2 - b_1)^2 + (c_2 - c_1)^2\right]^{\frac{1}{2}} \tag{11}$$

$$\cos \beta_1 = (b_2 - b_1)/\left[(a_2 - a_1)^2 + (b_2 - b_1)^2 + (c_2 - c_1)^2\right]^{\frac{1}{2}}$$

$$\cos \gamma_1 = (c_2 - c_1)/\left[(a_2 - a_1)^2 + (b_2 - b_1)^2 + (c_2 - c_1)^2\right]^{\frac{1}{2}}$$

The unit vector $\bar{j}'$ can now be obtained from the cross product

$$\bar{j}' = \bar{k}' \times \bar{i}' \tag{12}$$

or

$$\bar{j}' = \begin{bmatrix} \bar{i} & \bar{j} & \bar{k} \\ \cos \alpha_3 & \cos \beta_3 & \cos \gamma_3 \\ \cos \alpha_1 & \cos \beta_1 & \cos \gamma_1 \end{bmatrix} \tag{13}$$

which yields

$$\bar{j}' = (\cos \alpha_2)\ \bar{i} + (\cos \beta_2)\ \bar{j} + (\cos \gamma_2)\ \bar{k} \tag{14}$$

where

$$\begin{aligned}
\cos \alpha_2 &= \cos \beta_3 \cos \gamma_1 - \cos \beta_1 \cos \gamma_3 \\
\cos \beta_2 &= \cos \alpha_1 \cos \gamma_3 - \cos \alpha_3 \cos \gamma_1 \\
\cos \gamma_2 &= \cos \alpha_3 \cos \beta_1 - \cos \alpha_1 \cos \beta_3
\end{aligned} \tag{15}$$

The relationship between the inertial and beacon coordinate systems can be expressed as:

$$\begin{bmatrix} \bar{i}' \\ \bar{j}' \\ \bar{k}' \end{bmatrix} \begin{matrix} = \\ = \\ = \end{matrix} \begin{bmatrix} \cos \alpha_1 & \cos \beta_1 & \cos \gamma_1 \\ \cos \alpha_2 & \cos \beta_2 & \cos \gamma_2 \\ \cos \alpha_3 & \cos \beta_3 & \cos \gamma_3 \end{bmatrix} \begin{bmatrix} \bar{i} \\ \bar{j} \\ \bar{k} \end{bmatrix} \tag{16}$$

This matrix is orthogonal, so that the inverse matrix is equal to the transpose. Therefore,

$$\begin{bmatrix} \bar{i} \\ \bar{j} \\ \bar{k} \end{bmatrix} \begin{matrix} = \\ = \\ = \end{matrix} \begin{bmatrix} \cos \alpha_1 & \cos \alpha_2 & \cos \alpha_3 \\ \cos \beta_1 & \cos \beta_2 & \cos \beta_3 \\ \cos \gamma_1 & \cos \gamma_2 & \cos \gamma_3 \end{bmatrix} \begin{bmatrix} \bar{i}' \\ \bar{j}' \\ \bar{k}' \end{bmatrix} \tag{17}$$

It is now desirable to express the coordinates of the beacons in the beacon coordinate system (x', y', z') as functions of the beacon coordinates in the inertial system. From our selected geometry we have

$$B_1\ (a_1, b_1, c_1);\ B_2\ (a_2, b_2, c_2);\ B_3\ (a_3, b_3, c_3) \tag{18}$$

in the inertial coordinate frame, while

$$B_1\ (o, o, o);\ B_2\ (a_2', o, o,);\ B_3\ (a_3', b_3', o) \tag{19}$$

in the beacon coordinate system. Thus,

$$\overrightarrow{B_1 B_2} = \overrightarrow{OB_2} - \overrightarrow{OB_1} = a_2'\ \bar{i}' = \bar{i}\,(a_2 - a_1) + \bar{j}\ (b_2 - b_1) + \bar{k}\ (c_2 - c_1) \tag{20}$$

taking the scalar product of this and $\bar{i}'$ obtained from equation (16) we have the result,

$$(a_2'\ \bar{i}') \cdot \bar{i}' = a_2' = \quad (a_2 - a_1)^2 + (b_2 - b_1)^2 + (c_2 - c_1)^2 \quad ^{\frac{1}{2}} \tag{21}$$

Similarly, taking the scalar product of $\overrightarrow{B_1 B_3}$ with both $\bar{i}'$ and $\bar{j}'$ from equation (16) we have

$$(\overrightarrow{B_1 B_3}) \cdot \bar{i}' = (a_3' \bar{i}' + b_3' \bar{j}') \cdot \bar{i}' = a_3' \qquad (22)$$

$$(\overrightarrow{B_1 B_3}) \cdot \bar{j}' = (a_3' \bar{i}' + b_3' \bar{j}') \cdot \bar{j}' = b_3'$$

or

$$a_3' = (a_3 - a_1) \cos \alpha_1 + (b_3 - b_1) \cos \beta_1 + (c_3 - c_1) \cos \gamma_1 \qquad (23)$$

$$b_3' = (a_3 - a_1) \cos \alpha_2 + (b_3 - b_1) \cos \beta_2 + (c_3 - c_1) \cos \gamma_2$$

COORDINATES OF THE PROJECTILE

At any instant of time during the flight, let the coordinates of the projectile be (x, y, z) in the inertial coordinate system, and (x′, y′, z′) in the beacon coordinate system. Similarly, the target locations at any time are (a_T, b_T, c_T) and (a_T', b_T', c_T'), as shown in figure 3. The time of arrival (TOA) or distance measuring equipment (DME) measured distances from the projectile to beacons B_1, B_2, and B_3 are R_1, R_2, and R_3, respectively.

These ranges can be expressed in terms of the projectile position as:

$$R_1^2 = (x')^2 + (y')^2 + (z')^2 \qquad (24)$$

$$R_2^2 = (x' - a_2')^2 + (y')^2 + (z')^2$$

$$R_3^2 = (x' - a_3')^2 + (y' - b_3')^2 + (z')^2$$

The projectile can be located by a sequential solution of the foregoing equations in the following manner:

$$R_1^2 - R_2^2 = 2a_2' x' - (a_2')^2 \qquad (25)$$

or,

$$x' = \left[R_1^2 - R_2^2 + (a_2')^2 \right] / 2a_2' \qquad (26)$$

Similarly,

$$R_1^2 - R_3^2 = 2a_3' x' - (a_3')^2 + 2 b_3' y' - (b_3')^2 \qquad (27)$$

or

$$y' = \left[R_1^2 - R_3^2 + (a_3')^2 + (b_3')^2 - 2a_3' x' \right] / 2b_3' \qquad (28)$$

and finally,

$$z' = \pm\sqrt{R_1^2 - (x')^2 - (y')^2} \tag{29}$$

With the projectile location now known in the beacon coordinate system, we note that

$$\overrightarrow{OP} = \overrightarrow{OB_1} + \overrightarrow{B_1P} \tag{30}$$

or

$$x\,\bar{i} + y\,\bar{j} + z\,\bar{k} = (a_1\,\bar{i} + b_1\,\bar{j} + c_1\,\bar{k}) + (x'\,\bar{i}' + y'\,\bar{j}' + z'\,\bar{k}') \tag{31}$$

Substituting equation (16) into equation (31) and solving for the inertial coordinates of the projectile, we have

$$\begin{aligned} x &= a_1 + x' \cos\alpha_1 + y' \cos\alpha_2 + z' \cos\alpha_3 \\ y &= b_1 + x' \cos\beta_1 + y' \cos\beta_2 + z' \cos\beta_3 \\ z &= c_1 + x' \cos\gamma_1 + y' \cos\gamma_2 + z' \cos\gamma_3 \end{aligned} \tag{32}$$

the inverse of which is

$$\begin{aligned} x' &= (x - a_1) \cos\alpha_1 + (y - b_1) \cos\beta_1 + (z - c_1) \cos\gamma_1 \\ y' &= (x - a_1) \cos\alpha_2 + (y - b_1) \cos\beta_2 + (z - c_1) \cos\gamma_2 \\ z' &= (x - a_1) \cos\alpha_3 + (y - b_1) \cos\beta_2 + (z - c_1) \cos\gamma_3 \end{aligned} \tag{33}$$

Now, the projectile to target vector $\overrightarrow{PT}$ can be shown to be

$$\overrightarrow{PT} = \overrightarrow{OP} - \overrightarrow{OT} = (x - a_T)\,\bar{i} + (y - b_T)\,\bar{j} + (z - c_1)\,\bar{k} \tag{34}$$

or

$$\overrightarrow{PT} = O'P - O'T = (x' - a_T')\,\bar{i}' + (y' - b_T')\,\bar{j}' + (z' - c_T')\,\bar{k}' \tag{35}$$

The results of either equation (34) or (35) can be utilized for guidance purposes. In this report, equation (34) is used in order to simplify the projectile equations of motion.

It should be noted at this time, that equation (29) is ambiguous with respect to the projectile altitude in the beacon coordinate system. This result is readily understandable when we consider that the solution to the projectile location problem consists of finding the loci or intersection of three non-colinear spheres with different radii, which, for the general case, results in two discrete points.

To resolve this ambiguity, consider when the projectile is at time $t = t_0$, the start of active guidance. At this time, the altitude in the inertial system was assumed to be roughly the apogee of the ballistic trajectory. At this point, we can estimate the projectile position (x, y, z) in the inertial system from a simple ballistic solution, and since we know, a priori, the values of a_1, b_1, c_1, $\cos \alpha_3$, $\cos \beta_3$, and $\cos \gamma_3$, we can determine, with the use of equation (33), the algebraic sign of the projectile altitude in the beacon coordinate system. In addition, by continuity arguments, we can state that if z' decreases and ultimately changes sign (fig. 4) it does so smoothly, so that the sign of the calculated z' would change subsequent to every zero crossing.

TRAJECTORY CONSIDERATIONS AND PROJECTED PLANAR GUIDANCE SCHEME

It has been shown that the three-beacon range measuring system has the capability of determining the projectile coordinates and the projectile-to-target vector at any instant of time, in either coordinate system. Therefore, given perfect range measurements and true beacon and target locations, the achievable CEP at impact depends on the chosen guidance law coupled with the projectile dynamics and the altitudes at the start and termination of guidance.

The simulation developed in subsequent sections permits a comparative evaluation of different navigation schemes for a point-mass projectile, with provisions for modeling bias-type errors in beacon and target locations and random errors in range measurements.

Sandia (ref. 1) has reported that a "projected planar guidance" scheme is superior to a proportional navigation system when used with pre-emplaced beacons. This guidance scheme can be explained with reference to figure 5.

The projectile is constrained to be steered in the x - y plane only, utilizing the command signals $(x(t) - a_T)$, and $(y(t) - b_T)$. Thus, the velocity of the projectile in the x - y plane becomes

$$\overrightarrow{V_P} = \frac{d}{dt} \left[x(t) - a_T \right] \bar{i} + \frac{d}{dt} \left[y(t) - b_T \right] \bar{j} \tag{36}$$

or

$$\overrightarrow{V_P} = \dot{x}(t) \, \bar{i} + \dot{y}(t) \, \bar{j} \tag{37}$$

In the projected planar guidance scheme, the planar projectile velocity is smoothly decreased during the guidance phase so that at the termination of guidance, $t = t_f$,

$$
\begin{aligned}
\dot{x}(t_f) &= o \\
\ddot{x}(t_f) &= o \\
\dot{y}(t_f) &= o \\
\ddot{y}(t_f) &= o \\
x(t_f) - a_t &= o \\
y(t_f) - b_t &= o
\end{aligned}
\tag{38}
$$

At termination of guidance, the projectile is at a point directly above the target, with zero planar velocity and acceleration. For the remainder of the trajectory, the projectile falls vertically with respect to the x - y inertial plane, until target impact.

Equation (38) indicates that this scheme makes no use of the altitude information, which can be provided by the three-beacon system. So, in essence, a data item is being discarded by the scheme despite the chance that its inclusion may result in improved guidance accuracy.

THE PROJECTILE EQUATIONS OF MOTION AND THE PROJECTED PLANAR GUIDANCE LAW

Projectile Equations of Motion

A flat-earth, three-degrees-of-freedom point mass model was assumed for the projectile with drag, $\bar{F}_D$, gravity, mg, and applied control forces, F_x, F_y, and F_z, as shown in figure 6.

From Newton's Law,

$$\bar{F} = m\,\bar{a} \tag{39}$$

where

$$\bar{F} = \bar{F}_G + \bar{F}_D + F_X\,\bar{i} + F_Y\,\bar{j} + F_Z\,\bar{k} \tag{40}$$

and

$$\bar{a} = \frac{d^2}{dt^2}\,\bar{R} = \frac{d^2}{dt^2}\left[x\bar{i} + \bar{y} + z\bar{k}\right] \tag{41}$$

or

$$\bar{a} = \ddot{x}\,\bar{i} + \ddot{y}\,\bar{j} + \ddot{z}\,\bar{k} \tag{42}$$

Thus, the gravity force is,

$$\bar{F}_G = -(mg)\,\bar{k} \tag{43}$$

and the drag force is

$$\bar{F}_D = -\tfrac{1}{2}\rho V^2 C_D A\,\bar{u}_V$$

where

$$\bar{u}_V = \frac{\bar{V}}{V} = \frac{\dot{x}}{V}\,\bar{i} + \frac{\dot{y}}{V}\,\bar{j} + \frac{\dot{z}}{V}\,\bar{k} \tag{44}$$

so that

$$\bar{F}_D = -\tfrac{1}{2}\rho\, C_D A V\left[\dot{x}\,\bar{i} + \dot{y}\,\bar{j} + \dot{z}\,\bar{k}\right] \tag{45}$$

Substituting equations (43) and (45) into equation (40) and (42) into equation (39) and solving for the component accelerations, we have,

$$\ddot{x} = \frac{F_x}{m} - \tfrac{1}{2}\rho\,\frac{C_D A}{m}\,V\dot{x} \tag{46}$$

$$\ddot{y} = \frac{F_y}{m} - \tfrac{1}{2}\rho\,\frac{C_D A}{m}\,V\dot{y}$$

$$\ddot{z} = \frac{F_z}{m} - g - \tfrac{1}{2}\rho\,\frac{C_D A}{m}\,V\dot{z}$$

$$V = \left[(\dot{x})^2 + (\dot{y})^2 + (\dot{z})^2\right]^{\frac{1}{2}}$$

$$\rho = \rho_o e^{-\left(\frac{z}{22000}\right)}$$

where m = Projectile mass

A = Projectile cross-sectional area

g = Acceleration of gravity

ρ = Air density at altitude z

ρ_o = Air density at sea level

C_D = Coefficient of drag

F_x, F_y, F_z = Applied control forces

$\dot{x}$, $\dot{y}$, $\dot{z}$ = Projectile component velocities

$\ddot{x}$, $\ddot{y}$, $\ddot{z}$ = Projectile component accelerations

The Navigation Law

The particular guidance scheme studied in this report was the projected planar guidance scheme as reported by Sandia (Ref. 1). In this scheme, F_z is assumed to be zero, while F_x and F_y are each linearly proportional to a combination of their respective position and velocity commands. This results in

$$\frac{F_x}{m} = K_P\, e_x + K_v\, \dot{e}_x \tag{47}$$

$$\frac{F_y}{M} = K_p\, e_y + K_v\, \dot{e}_y$$

$$F_z = 0$$

Where

$$e_x = x(t) - a_T \tag{48}$$

$$e_y = y(t) - b_T$$

The equations for the three-beacon system, as previously developed, provide e_x and e_y directly, but do not provide their derivatives. The required derivatives can be approximated by a lead-lag network that has a transfer function of the form

$$\frac{K_v s}{1 + \frac{s}{\lambda}} \tag{49}$$

where λ is selected to be large, when compared with the frequency content of the command signals, e_x and e_y.

Combining equation (49) and equation (47) we obtain the transfer function of the navigation controller

$$\frac{F_x}{m} = \left[K_p + \frac{K_v s}{1 + \frac{s}{\lambda}}\right] e_x \tag{50}$$

$$\frac{F_y}{M} = \left[K_p + \frac{K_v s}{1 + \frac{s}{\lambda}}\right] e_y$$

SIMULATION PROCEDURE

The method of computer simulation is shown in block diagram form in figure 7.

Initial Computations

At the start of the simulation, the true beacon and true target coordinates,

$$a_i,\ b_i,\ c_i \qquad\qquad i = 1,\ 2,\ 3,\ T$$

with respect to the inertial reference frame are specified, as well as the bias error in beacon and target locations,

$$(a_i)_c = a_i + \Delta a_i$$

$$(b_i)_c = b_i + \Delta b_i \qquad\qquad i = 1,\ 2,\ 3,\ T$$

$$(c_i)_c = c_i + \Delta c_i$$

The bias errors, Δa_i, Δb_i, Δc_i, are modeled as independent, Gaussian random variables, with zero means and specified variances. These bias errors are obtained at the start of each simulation and are held constant for the duration of the simulation.

Using both the true and biased values, the true and calculated direction cosines are determined from equations (7), (11), and (15)

$$\cos\alpha_i,\ \cos\beta_i,\ \cos\gamma_i \qquad\qquad i = 1,\ 2, 3$$

$$(\cos\alpha_i)_c,\ (\cos\beta_i)_c,\ (\cos\gamma_i)_c \qquad i = 1,\ 2,\ 3$$

and the true and calculated beacon locations in the beacon reference frame are determined from equations (21) and (23)

$$a_2',\ a_3',\ b_3'$$

$$(a_2')_c,\ (a_3')_c,\ (b_3')_c$$

Dynamic Computations

During the dynamic simulation, the projectile equations of motion, equation (46), are integrated to determine the true location of the projectile

in the inertial reference frame (x, y, z). The coordinate transformation, given by equation (33), is then utilized to obtain the true projectile position with respect to the beacon reference frame (x', y', z'). The true ranges are then determined from equation (24).

Range measurement errors are then introduced by adding computer generated noise to each true range,

$$R_{i_m}(t) = R_i(t) + \varepsilon_{R_i}(t) \qquad i = 1, 2, 3$$

where each noise generator, $\varepsilon_{R_i}(t)$, is independent and produces Gaussian white noise, with zero mean and identical variance.

The projectile coordinate calculator then determines the calculated projectile position with respect to the beacon reference frame, utilizing the measured ranges, R_{i_m}, and the calculated beacon locations in the beacon reference frame, $(a_2')_c$, $(a_3')_c$, and $(b_3')_c$ in equations (26), (28), and (29).

The coordinate transformation given by equation (32) is then employed to arrive at the calculated projectile position in the inertial reference frame, which, along with the calculated target location $(a_{T_c}, b_{T_c}, c_{T_c})$, is used in equation (48) to determine the calculated steering inputs (e_{x_c}, e_{y_c}) to the steering control system. The control system then produces forces F_x and F_y, according to the relationship given in equation (50), to alter the projectile flight dynamics.

It should be noted that the extent of the computations required by the projectile's on-board processor are given by blocks 4 through 6 in figure 7. These are relatively simple, straight-forward calculations; however, they require the on-board storage of the calculated beacon locations in both the inertial and beacon reference frames, the calculated target location in the inertial frame, and the calculated direction cosines. These data must be calculated and furnished to the projectile processor prior to firing or during the early portion of the projectile flight prior to the start of active guidance.

Extension of the Simulation

The simulation method, as shown in figure 7, was developed to model the fixed beacon reference system.

The simulation as it exists, however, can be readily adapted to include beacons, each with its own proper motion. In this case, the beacon positions are allowed to vary with time, relative to the inertial reference frame. Thus, a_i, b_i, c_i, become $a_i(t)$, $b_i(t)$, $c_i(t)$, $i = 1, 2, 3$, where $a_i(t)$, $b_i(t)$ and $c_i(t)$ are known at any time. Beacon errors can then be viewed as true positions plus random errors, rather than as true positions plus bias errors, as indicated previously.

Similarly, the target location which was assumed to be fixed and known within a mapping bias error, can assume a proper motion by allowing its coordinates to vary with time, $a_T(t)$, $b_T(t)$, $c_T(t)$, with associated bias and random white noise errors.

In order to include a moving target scenario in the simulation, some mechanism must be postulated for measuring the target position as a function of time. Speculation as to the nature of this mechanism, however, is beyond the scope of this report.

STATIC SENSITIVITY AND ERROR ANALYSIS

The determination of the sensitivity of the impact CEP to beacon location errors is a prime objective of this study. The degree of sophistication of the guidance law is immaterial if the inherent inaccuracies introduced by the three-beacon guidance system cause the projectile to exceed the desired CEP at impact.

The impact CEP sensitivity of the three-beacon system when only errors in beacon location are considered. is investigated. This case is referred to as the static case.

Static CEP Sensitivity

In considering only beacon location errors, we make the following assumptions:

1. Range measurements are errorless

2. Target location is known exactly

3. The guidance system is ideal and capable of realizing the projected planar guidance trajectory exactly. Thus, the calculated trajectory will result in projectile impact at the target.

Although we know the target location exactly, the steering signals

$$e_x = x_c(t) - a_T \qquad (51)$$

$$e_y = y_c(t) - b_T$$

depend on the calculated projectile position (denoted by subscript "c"), which is in error due to the beacon location errors. Therefore, the calculated trajectory impacts at the true target location, T, while the true trajectory impacts at some other point, T_f, as shown in figure 8.

At $t = t_f$, the projectile is at some prescribed altitude, z_c, and the projected planar guidance will have achieved the following conditions:

$$x_c = a_T \qquad y_c = b_T \qquad (52)$$

$$\dot{x}_c = 0 \qquad \dot{y}_c = 0$$

$$x_c = 0 \qquad y_c = 0$$

The constraints imposed by equation (52) can be used to find the actual projectile position at $t = t_f$ as follows using equation (33)

$$x_c' = (a_T - a_{1_c}) \cos \alpha_{1_c} + (b_T - b_{1_c}) \cos \beta_{1_c} + (z_c - c_{1_c}) \cos \gamma_{1_c} \qquad (53)$$

$$y_c' = (a_T - a_{1_c}) \cos \alpha_{2_c} + (b_T - b_{1_c}) \cos \beta_{2_c} + (z_c - c_{1_c}) \cos \gamma_{2_c}$$

$$z_c' = (a_T - a_{1_c}) \cos \alpha_{3_c} + (b_T - b_{1_c}) \cos \beta_{3_c} + (z_c - c_{1_c}) \cos \gamma_{3_c}$$

The true ranges from the projectile to the beacons can then be found by

$$R_1^2 = (x_c')^2 + (y_c')^2 + (z_c')^2 \qquad (54)$$

$$R_2^2 = (x_c' - a_{2_c}')^2 + (y_c')^2 + (z_c')^2$$

$$R_3^2 = (x_c' - a_{3_c}')^2 + (y_c' - b_{3_c}')^2 + (z_c')^2$$

We can now obtain the actual projectile position in the beacon-based coordinate system

$$x' = \frac{R_1^2 - R_2^2 + (a_2')^2}{2a_2'} \tag{55}$$

$$y' = \frac{R_1^2 - R_3^2 + (a_3')^2 + (b_3')^2 - 2a_3' x'}{2b_3'}$$

$$z' = \sqrt{R_1^2 - (x')^2 - (y')^2}$$

Thus, the actual projectile position in the inertial reference frame is

$$\begin{aligned} x &= a_1 + x' \cos\alpha_1 + y' \cos\alpha_2 + z' \cos\alpha_3 \\ y &= b_1 + x' \cos\beta_1 + y' \cos\beta_2 + z' \cos\beta_3 \\ z &= c_1 + x' \cos\gamma_1 + y' \cos\gamma_2 + z' \cos\gamma_3 \end{aligned} \tag{56}$$

The coordinates of the actual projectile impact are given by equation (56), if the constraints of equation (52) are satisfied for the true trajectory. Since the guidance system calculations are based upon the calculated trajectory, the constraints of equation (52) will not, for the general case, be satisfied, since $\dot{x}$ and $\dot{y}$ at $t = t_F$ are non-zero quantities. The actual impact point of the true trajectory can be computed by integrating the ballistic equations of motion for $t > t_F$, using the actual position and velocity at $t = t_F$ as the initial conditions.

Rather than pursuing this line of computation, we can obtain more easily an approximate determination of the true point of impact. At $t = t_F$, z is relatively small compared to the maximum ordinate of the trajectory, so that it can be assumed that $\dot{x}$, $\dot{y}$, and $\dot{z}$ are essentially constant from $t = t_F$ to impact. Due to the geometry of the trajectory, at $t = t_F$

$$\dot{z} \gg \dot{x},\ \dot{y} \tag{57}$$

We can assume that the total velocity is essentially $\dot{z}(t_f)$. Since the calculated trajectory closely approximates the true trajectory, we can state that

$$\dot{z}(t_f) \cong \dot{z}_c(t_f),\ z(t_f) \cong z_c(t_f) \tag{58}$$

Thus, the approximate time to impact, Δt, can be calculated as

$$\Delta t = \left. \frac{z_c}{\dot{z}_c} \right|_{t = t_f} \tag{59}$$

Then, the impact point is given by

$$x_I = x(t_f) + \dot{x}(t_f)\ \Delta t \tag{60}$$

$$y_I = y(t_f) + \dot{y}(t_f)\ \Delta t$$

and the planar impact error at the target is

$$\rho_T = \sqrt{(x_I - a_T)^2 + (y_I - b_T)^2} \tag{61}$$

The projectile position at $t = t_f$ is obtained by utilizing equations (53) to (56), while the velocities $\dot{x}(t_f)$, $\dot{y}(t_f)$, and $\dot{z}(t_f)$ are obtained in the following manner:

Differentiating equation (53) we have

$$\dot{x}_c' = \dot{z}_c\ (\cos \gamma_1)_c \tag{62}$$

$$\dot{y}_c = \dot{z}_c\ (\cos \gamma_2)_c$$

$$\dot{z}_c = \dot{z}_c\ (\cos \gamma_3)_c$$

Next, differentiating equation (54) and utilizing the results of equation (62), we have

$$2\, R_1 \dot{R}_1 = 2\, \dot{z}_c \left[x_c'\ (\cos \gamma_1)_c + y_c'\ (\cos \gamma_2)_c + z_c'\ (\cos \gamma_3)_c \right] \tag{63}$$

$$2\, R_2 \dot{R}_2 = 2\, \dot{z}_c \left[(x_c' - a_{2_c}')(\cos \gamma_1)_c + y_c'\ (\cos \gamma_2)_c + z_c'\ (\cos \gamma_3)_c \right]$$

$$2\, R_3 \dot{R}_3 = 2\, \dot{z}_c \left[(x_c' - a_{3_c}')\ (\cos \gamma_1)_c + (y_c' - b_{3_c}')\ (\cos \gamma_2)_c + z_c'\ (\cos \gamma_3)_c \right]$$

Differentiating equation (55) and utilizing the results of equation (63), we have

$$\dot{x}' = (a'_{2_C}/a'_2)\ \dot{z}_C\ (\cos\gamma_1)_C \tag{64}$$

$$\dot{y}' = \dot{z}_C\left\{(b'_{3_C}/b'_3)\ (\cos\gamma_2)_C + (1/b'_3)\left[a'_{3_C} - a'_3\ (a'_{2_C}/a'_2)\right](\cos\gamma_1)_C\right\}$$

$$\dot{z}' \cong \dot{z}'_C = \dot{z}_C\ (\cos\gamma_3)_C$$

Finally, differentiating equation (56) and using the results of equation (64) we have,

$$\dot{x} = \dot{z}_C\left\{\left(\frac{a'_{2_C}}{a'_2}\right)\cos\alpha_1\ (\cos\gamma_1)_C + \left(\frac{b'_{3_C}}{b'_3}\right)\cos\alpha_2\ (\cos\gamma_2)_C + \left(\frac{1}{b'_3}\right)\right. \tag{65}$$

$$\left.(a'_{3_C} - \frac{a'_3\ a'_{2_C}}{a'_2})\cos\alpha_2\ (\cos\gamma_1)_C + \cos\alpha_3\ (\cos\gamma_3)_C\right\}$$

$$\dot{y} = \dot{z}_C\left\{\left(\frac{a'_{2_C}}{a'_2}\right)\cos\beta_1\ (\cos\gamma_1)_C + \left(\frac{b'_{3_C}}{b'_3}\right)\cos\beta_2\ (\cos\gamma_2)_C + \left(\frac{1}{b'_3}\right)\right.$$

$$\left.(a'_{3_C} - \frac{a'_3\ a'_{2_C}}{a'_2})\cos\beta_2\ (\cos\gamma_1)_C + \cos\beta_3\ (\cos\gamma_3)_C\right\}$$

Thus we can obtain the planar velocities at $t = t_f$ in terms of the calculated vertical velocity, $\dot{z}_C$, the true and calculated beacon locations in the beacon coordinate system, a'_2, a'_3, b'_3, a'_{2_C}, a'_{3_C}, b'_{3_C}, and the direction cosines between the beacon and inertial reference frames, $\cos\alpha_i$, $\cos\beta_i$, $\cos\gamma_i$, $i = 1, 2, 3$.

Error Statistics

Beacon Errors

We have assumed that the components of the beacon location error are Δx, Δy, and Δz. These component errors are modeled as independent Gaussian random variables, with zero mean and equal variance, σ_B^2. The spherical beacon error is taken as

$$\rho_B = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2} \tag{66}$$

For the Gaussian model assumed above, the probability density function for ρ_B is

$$f_B(\rho_B) = \sqrt{\frac{2}{\pi}}\,\frac{\rho_B^{\,2}}{\sigma_B^{\,3}}\ \mathrm{EXP}\left\{-\frac{\rho_B^{\,2}}{2\rho_B^{\,2}}\right\} \tag{67}$$

This distribution is characterized by

$$\text{average } \{\rho_B\} = \bar{\rho}_B = 2\sqrt{\frac{2}{\pi}}\ \sigma_B = 1.60\ \sigma_B \tag{68}$$

and

$$\text{CEP } \{\rho_B\} = 1.54\ \sigma_B \tag{69}$$

where CEP $\{\rho_B\}$ is derived from ρ_B by

$$P\left\{\rho_B \leqslant \text{CEP }(\rho_B)\right\} = 0.5 \tag{70}$$

Target Impact Errors

At the time of impact, the coordinates of the impact error are

$$(\Delta x)_T = x_I - a_T \tag{71}$$
$$(\Delta y)_T = y_I - b_T$$

and the planar circular error is

$$\rho_T = \sqrt{(\Delta x)_T^2 + (\Delta y)_T^2} \tag{72}$$

At this point, we will assume that $(\Delta x)_T$ and $(\Delta y)_T$ can be approximated by independent Gaussian random variables, with zero mean and equal variance. This implies that ρ_T is Rayleigh distributed with a probability density function of the form

$$f_T(\rho_T) = \frac{\rho_T}{\sigma_T^2}\ \mathrm{EXP}\left\{-\frac{\rho_T^2}{2\sigma_T^2}\right\} \tag{73}$$

This distribution is characterized by

$$\text{average } \{\rho_T\} = \bar{\rho}_T = 1.25\ \sigma_T \tag{74}$$

and

$$\text{CEP } \{\rho_T\} = 1.18\ \sigma_T \tag{75}$$

Utilizing both equations (74) and (75) we obtain

$$\text{CEP}\ \{\rho_T\} = 0.944\,\bar{\rho}_T \tag{76}$$

Dividing this by equation (69) we obtain

$$\frac{\text{CEP}\ \{\rho_T\}}{\text{CEP}\ \{\rho_B\}} = 0.613\left(\frac{\bar{\rho}_T}{\sigma_B}\right) \tag{77}$$

which gives the ratio of target-to-beacon CEP's as a function of average impact error and beacon standard deviation.

For the computer simulations, σ_B was specified, and the Δx, Δy, and Δz of the beacons were obtained by multiplying σ_B by the output of a random Gaussian distribution subroutine with a zero mean and a variance of 1. The average impact error, ρ_T, was then calculated, based on a large number of static simulations.

COMPUTER SIMULATION RESULTS

Static Simulation

Program and Parameters

A computer simulation was developed to implement equations (51) through (65). The program was written in FORTRAN Extended, Version 4, for use on a CDC 6600 computer system and used a proprietary CDC mathematic/statistical routine, NRAND, to generate normally distributed, pseudo-random numbers.

For the simulations considered, the beacon coordinate system is simply translated from the inertial reference system (no rotations involved). Thus, the locations of the three beacons and the target, relative to the inertial frame, are taken to be:

B_1 : (RX, RY, O)

B_2 : (RX + BS, RY, O)

B_3 : (RX, RY + BS, O)

T : (AT, BT, O)

The inputs to the program are:

ZF- Z_f, guidance cut-off altitude (meters)

VTERM - Projectile terminal velocity (meters/second)

SIGB - σ_B, beacon location standard deviation (meters)

BS - Beacon spacing (kilometer)

RX, RY - X and Y components of beacon #1 relative to inertial frame (meters)

C1, C2, C3, CT - Altitudes of beacons #1, #2, #3 and the target in the inertial reference frame (meters).

The program outputs were:

XBAR - Mean impact error (meters)

STDEV - Impact error standard deviation (meters)

RTCEP - Circular error probability (CEP) of the impact points about the target location (meters).

A listing of the computer program statements, as utilized, is given in figure 9. The input variables had the following values:

ZF - 0,500, 1000, 2000 meters

VTERM - 0, 200, 250, 300 meters/second

SIGB - 1, 4, 7, 10, 30, 50 meters

BS - 1, 2, 3, 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60 kilometers

RX, RY - 15,000 meters

C1, C2, C3, CT - 0 meters

Simulation Results

Appendix A presents the results of the static simulations. It should be noted that the results presented for each beacon spacing represents the statistical results obtained from 100 independent Monte-Carlo simulations for the indicated input parameters.

The ratio, CEP $\{\rho_T\}$/CEP $\{\rho_B\}$, as a function of beacon spacing and for fixed values of beacon location variance and projectile terminal velocity, is given in figure 10. It can be seen that for relatively close beacon spacing, an increase in the guidance cut-off altitude, ZF, produces a corresponding increase in impact error, which is consistent with the results of equation (60). It is interesting to note, however, that there exists a value of beacon spacing, $(BS)_{min}$, such that CEP $\{\rho_T\}$/CEP $\{\rho_B\}$ attains a minimum for all ZF and all BS $\geqslant (BS)_{min}$. Figure 11 is an expanded plot of a portion of Figure 10, and indicates that this beacon spacing is on the order of 10 kilometers.

Figure 12 presents CEP $\{\rho_T\}$/CEP $\{\rho_B\}$ as a function of guidance cut-off altitude and terminal velocity for fixed-beacon variance and beacon spacing. It appears that CEP $\{\rho_T\}$/CEP $\{\rho_B\}$ attains a minimum at different guidance cut-off altitudes for each of the terminal velocities considered. It can be seen, however, that the impact error over a 2000 meter increase in guidance cut-off altitude increases by only 11 percent. We can, therefore, state that the impact error as a function of guidance cutoff altitude is relatively insensitive to variations in projectile terminal velocity.

The variation of CEP $\{\rho_T\}$ as a function of CEP $\{\rho_B\}$ and terminal velocity for a fixed beacon spacing and guidance cut-off altitude is presented in figure 13. It can be seen from this that CEP $\{\rho_T\}$ varies linerary with respect to CEP $\{\rho_B\}$ and is independent of terminal velocity.

Dynamic Simulation

Program and Parameters

Dynamic simulation of a typical projectile employing projected planar guidance and three beacons was implemented on a CDC 6600 computer utilizing CDC's Continuous System Simulation Language III (CSSL 3). This is a computer program designed to facilitate the representation and simulation of continuous dynamic systems. The language provides simple and straight forward programming of problems involving differential equations as opposed to an equivalent FORTRAN program.

Beacon location errors are obtained from a Gaussian random-number CSSL3 subroutine at the start of each simulation and then held constant for the duration of the run. Each beacon error is independent of the other.

Ranging errors from the projectile to the beacons are obtained from the random number subroutine and are inputted at each computation interval during the run. These simulated ranging errors are made independently beacon-to-beacon.

Figure 14 presents a listing of the CSSL3 simulation program.

The program inputs are as follows:

VO - Projectile muzzle velocity (meter/second)

QE - Quadrant elevation (mils)

AZ - Firing azimuth (mils)

A - Projectile cross-sectional area (meters)

XMASS - Projectile mass (kilograms)

AT, BT, CT - Location of target relative to gun position (meters)

A1, B1, C1; A2, B2, C2; A3, B3, C3 - Locations of beacons #1, #2, #3, respectively, relative to gun position (meters)

SIGMA - Standard deviation of beacon location error

RSIG - Standard deviation of ranging error

P, Q - Coefficients of the guidance transfer function

The program outputs were:

X, Y, Z - Projectile location with respect to the gun position (meters)

T - Projectile flight time (seconds)

For all simulations, the following parameters were fixed at the values indicated:

Muzzle velocity - 555.2 meters/seconds

Quadrant elevation - 804.9 mils

Firing azimuth - 800.0 mils

Beacon variance - 5.0 meters

Range variance - 25.0 meters

Beacon spacing - 5 kilometers

Twenty simulations were run for each of the following four cases:

Case I - Control errors only

Case II - Control and beacon bias errors

Case III - Control and ranging errors

Case IV - Control, beacon bias, and ranging errors

and for each of the following two target geometries:

Geometry I - Target within triangle formed by beacon locations.

Geometry II - Target outside triangle formed by beacon locations.

Simulation Results

Appendix B presents the results of the dynamic simulations for each error case and target location. The target CEP is calculated using equation 75.

Figure 15 shows the CEP at the target for Case I errors for both target geometries. The CEP for this case is quite small, on the order of 0.44 meters, but not actually zero. This error can be reduced by optimizing the control system parameters.

Figure 16 presents a plot of the impact points and CEP about the target for error Case II and Geometry I. The calculated CEP for this case is 7.5 meters. Figure 17 presents the results for error Case III, Geometry I. The calculated CEP is 11.2 meters.

Figure 18 presents the results for error Case IV, Geometry I. The calculated CEP is 14.5 meters.

As can be seen from figures 15 to 18, errors due to beacon bias and ranging are roughly comparable and an order of magnitude larger than control errors for this particular geometry. It can also be seen that the total system CEP is not the summation of the CEP's due to the individual errors. That is,

$$(\rho_{CEP})_{\text{Case IV}} \neq \left[(\rho_{CEP})_{\text{Case III}} - (\rho_{CEP})_{\text{Case I}} \right] + \left[(\rho_{CEP})_{\text{Case II}} - (\rho_{CEP})_{\text{Case I}} \right] + (\rho_{CEP})_{\text{Case I}}$$

Although Geometry I is a reasonable case to assume, it does not reflect the expected deployment of this type of projectile guidance system. The expected deployment of the guidance beacons would have all three beacons located to one side of the front edge of the battle area (FEBA) while the target is located on the other side of the FEBA. This senario was simulated by placing the target outside of the triangle formed by the beacon locations and it resulted in Geometry II.

Figure 15 and figures 19 through 21 present the results for error Cases I through IV with Geometry II. The calculated CEP's for each case are given below:

Case I	CEP = 0.44 meters
Case II	CEP = 14.7 meters
Case III	CEP = 13.3 meters
Case IV	CEP = 19.6 meters

It can be readily seen that the increase in system CEP for Geometry II is due mainly to the increase in error contributed by beacon bias. This is apparent since small errors in direction cosine computation result in larger impact errors in Geometry II than in Geometry I due to the increased beacon-to-target ranges encountered in Geometry II.

CONCLUSIONS

1. The feasibility of accurately locating a projectile in space utilizing a three-beacon guidance system has been shown.

2. The projected planar guidance scheme as utilized by Sandia (ref. 1) appears feasible to be used in conjunction with the three-beacon guidance system.

3. Beacon and target location accuracies of $\pm$ 5 meters in each axis are acceptable. It can be expected that beacon location accuracies on the order of $\pm$ 0.1 meter can be achieved by utilizing standard artillery surveying techniques (ref. 2).

4. Effects of beacon spacing and target location, with respect to the beacons, appear to be the most significant parameters effecting the achieveable CEP about the target.

RECOMMENDATIONS

Further effort should be directed toward evaluating conceptual, extended-range projectiles utilizing the three-beacon guidance system. Included in this effort should be the choice and optimization of a particular control scheme, the determination of an optimum control law, the modification of the projectile equations of motion to include all known aerodynamic effects, and the upgrading of the dynamic simulation from a three to six-degree-of-freedom program.

REFERENCES

1. George S. Bennett, *Beacon Guidance Analysis*, Sandia Laboratories Report, SAND 76-0204, Albuquerque, NM, June 1976

2. Department of the Army, *FM6-2 Field Artillery Survey*, US Government Printing Office, June 1970

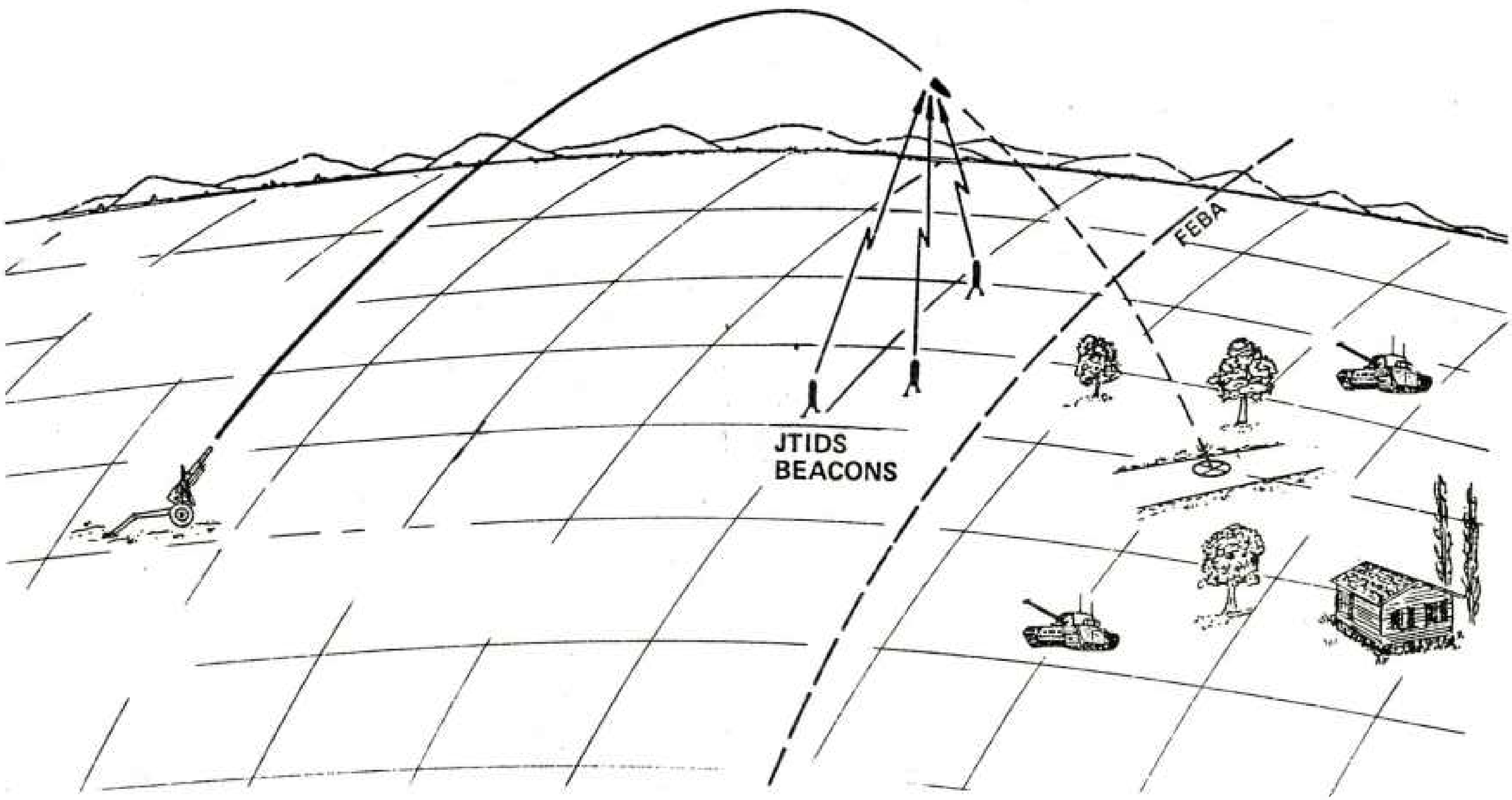

Figure 1. Artist's concept of three beacon land-based projectile guidance system

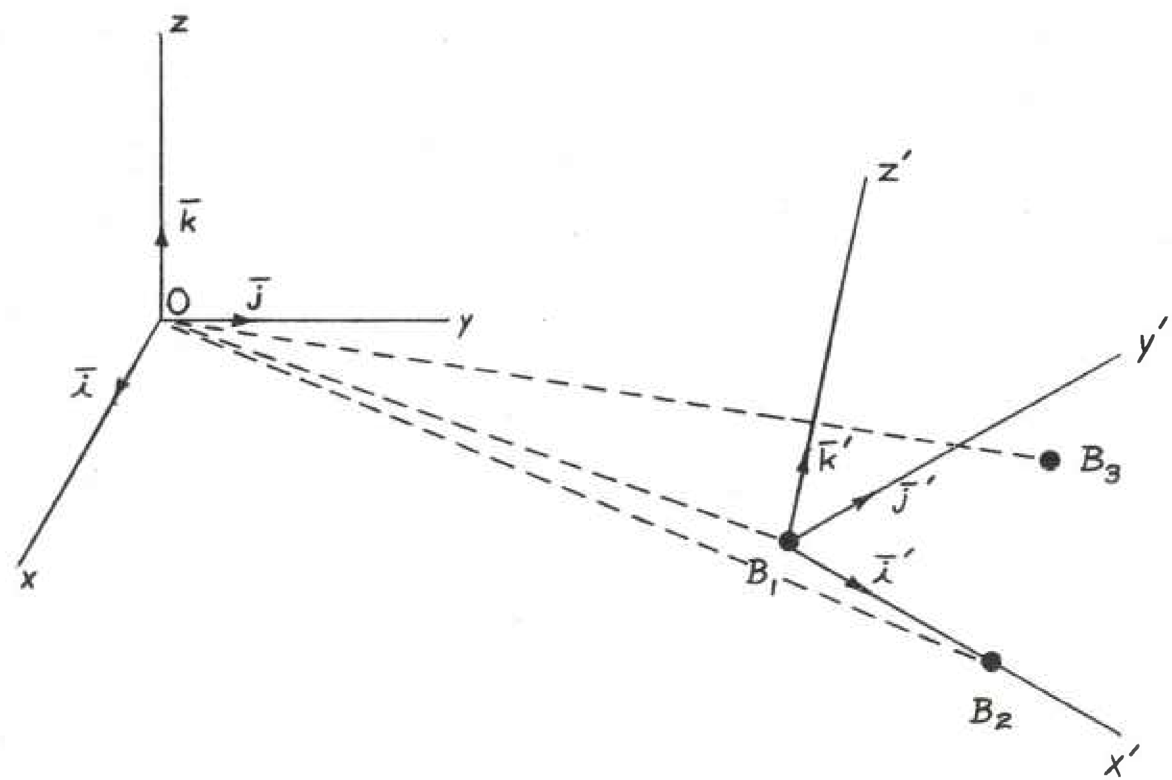

Figure 2. Geometry of the three-beacon system

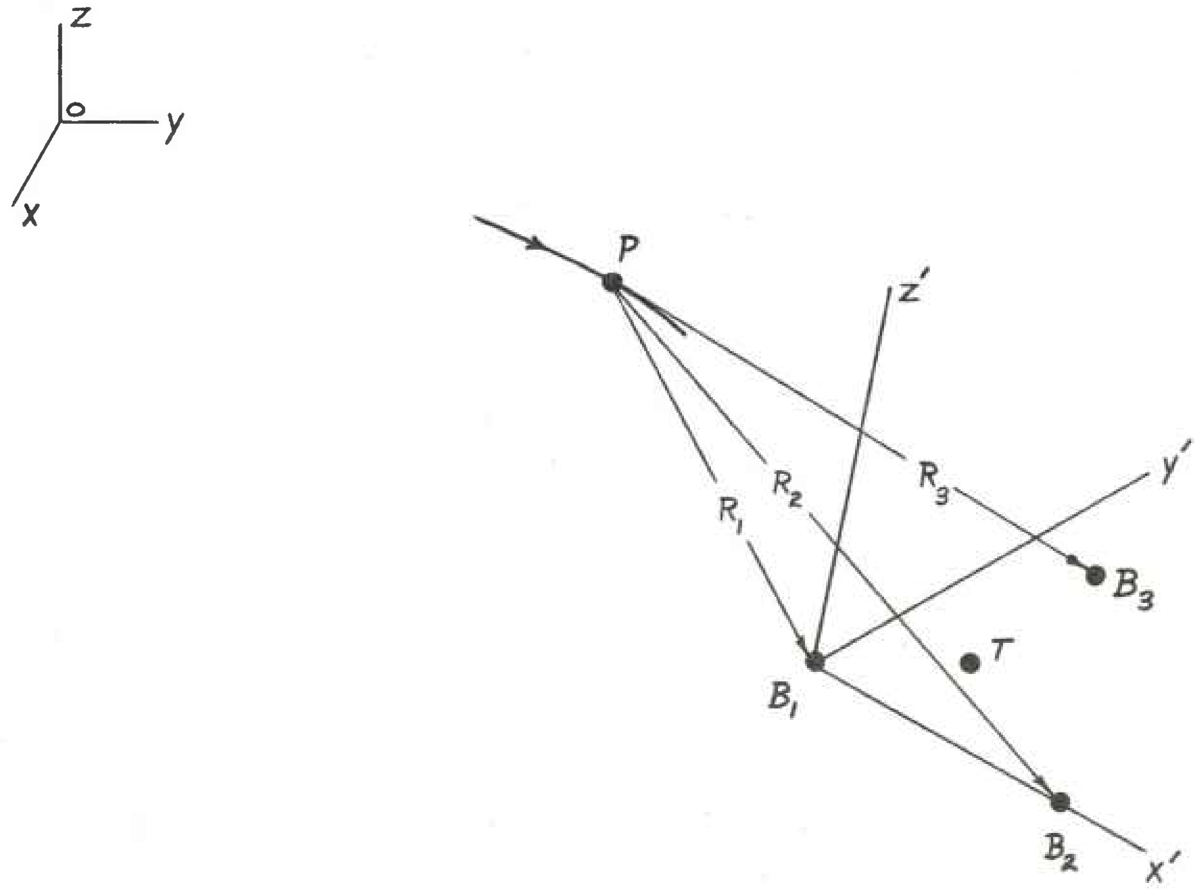

Figure 3. Projectile, target and beacon relationship

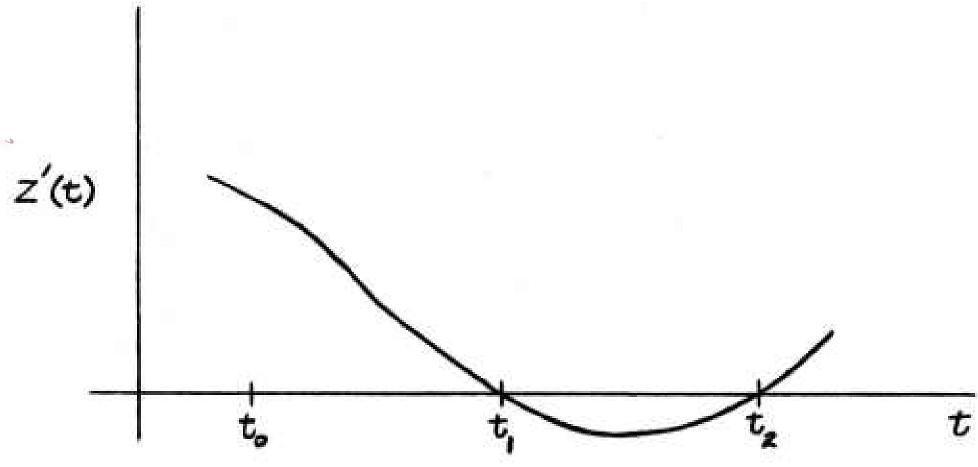

Figure 4. Altitude in the beacon coordinate system as a function of time

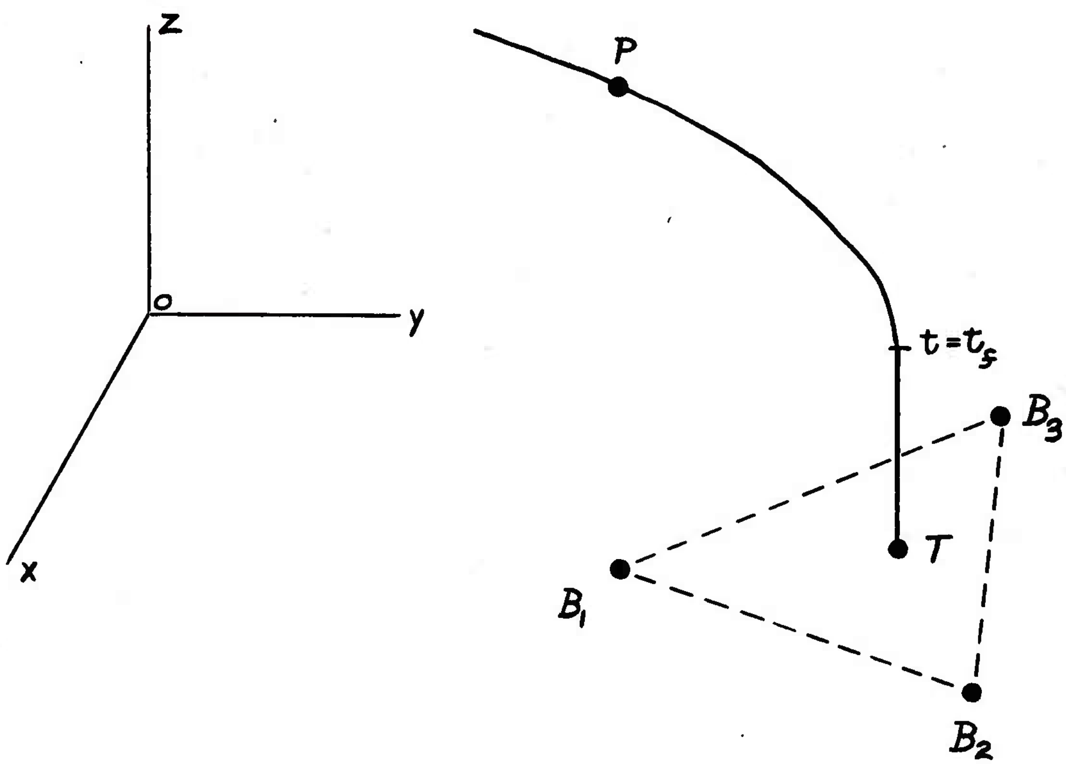

Figure 5. Projected planar guidance scheme

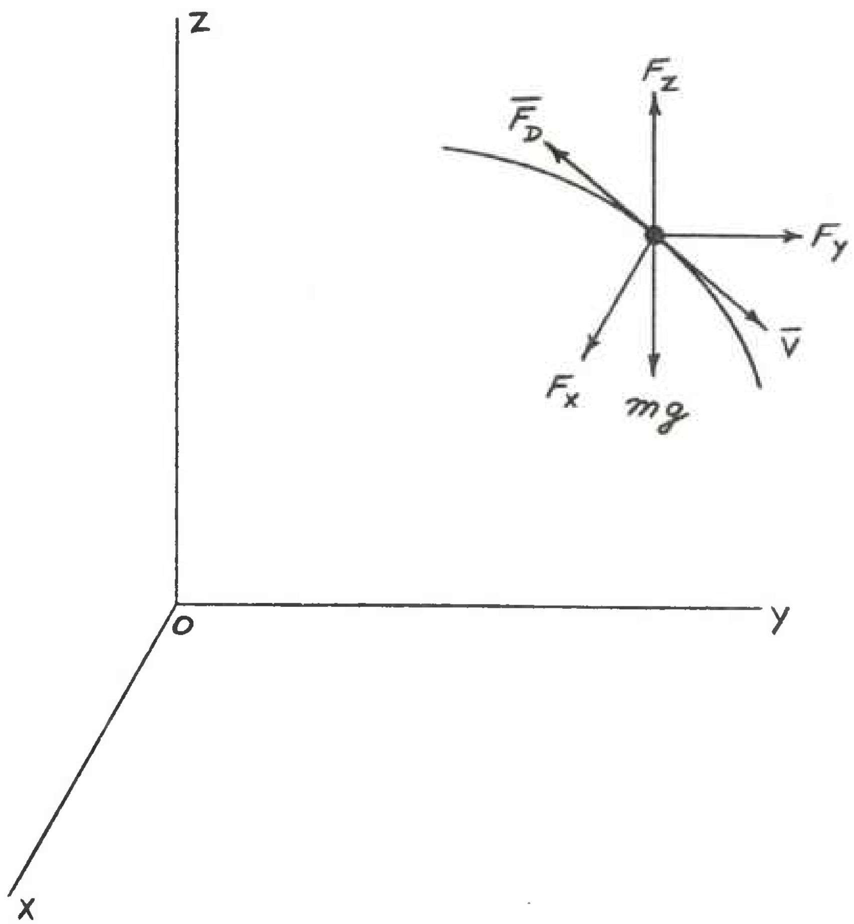

Figure 6. Forces acting on a point-mass projectile

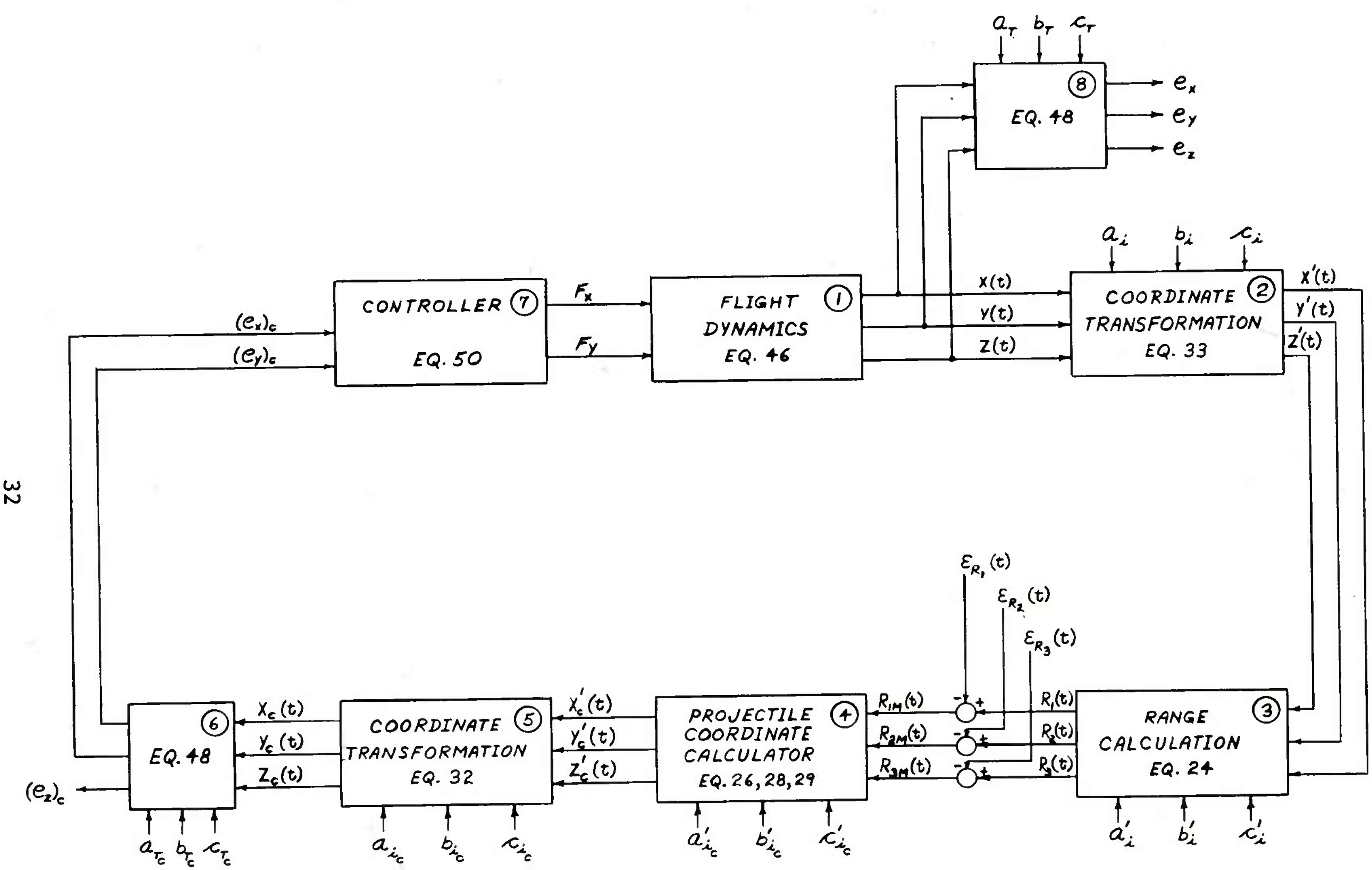

Figure 7. Three-beacon projected planar guidance simulation block diagram

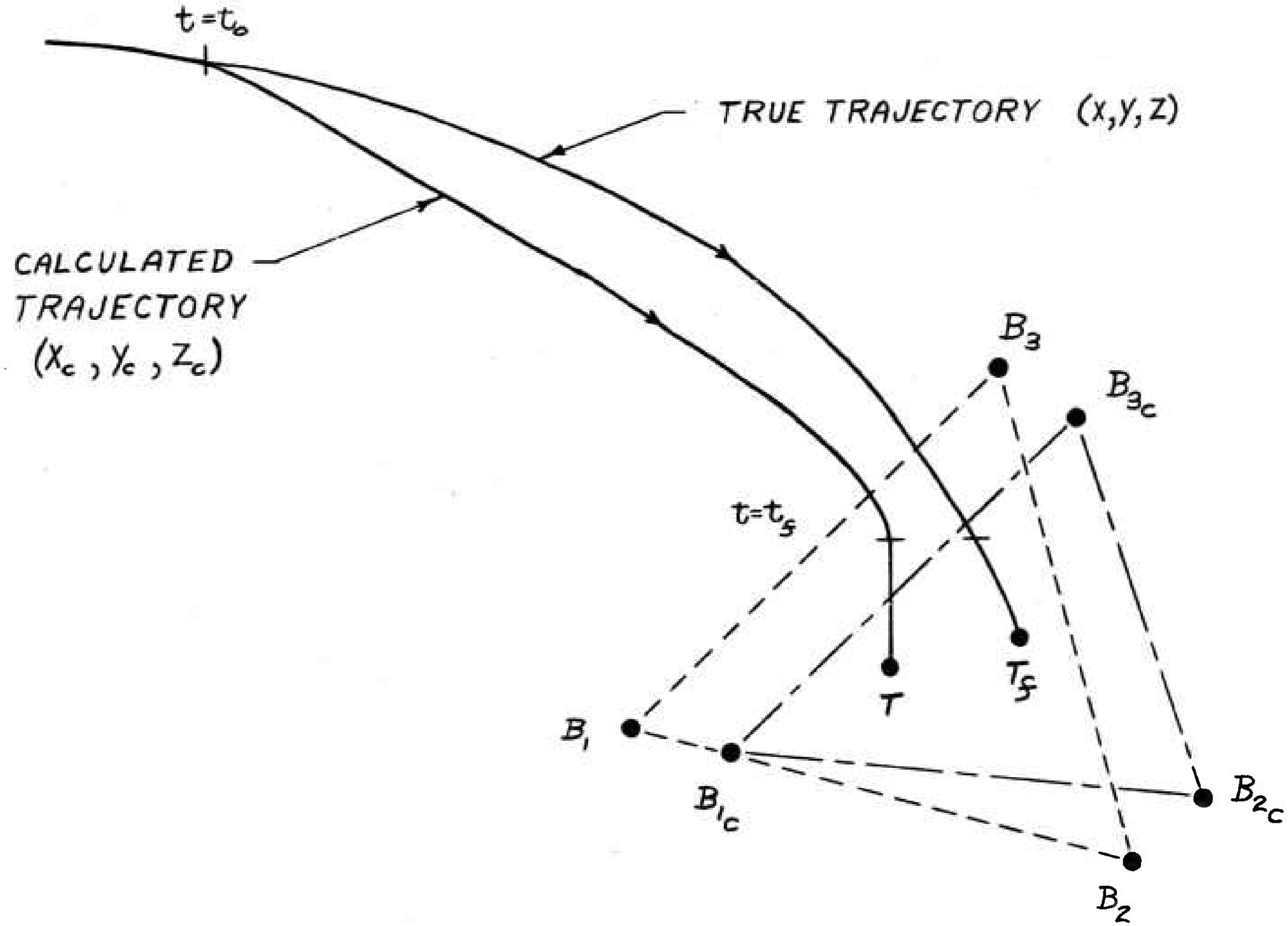

Figure 8. Actual and calculated projectile trajectories

```
      K=0
      SUM=0.
      DO 20 J=1,900,9
      A1C=A1+RND(J)*SIGB(LL)
      B1C=B1+RND(J+1)*SIGB(LL)
      C1C=C1+RND(J+2)*SIGB(LL)
      A2C=A2+RND(J+3)*SIGB(LL)
      B2C=B2+RND(J+4)*SIGB(LL)
      C2C=C2+RND(J+5)*SIGB(LL)
      A3C=A3+RND(J+6)*SIGB(LL)
      B3C=B3+RND(J+7)*SIGB(LL)
      C3C=C3+RND(J+8)*SIGB(LL)
      AC=(B2C-B1C)*(C3C-C1C)-(B3C-B1C)*(C2C-C1C)
      BC=(A2C-A1C)*(C2C-C1C)-(A2C-A1C)*(C3C-C1C)
      CC=(A2C-A1C)*(B3C-B1C)-(A3C-A1C)*(B2C-B1C)
      EC2=AC**2+BC**2+CC**2
      EC=SQRT(EC2)
      COSA3C=AC/EC
      COSB3C=BC/EC
      COSG3C=CC/EC
      A2PC2=(A2C-A1C)**2+(B2C-B1C)**2+(C2C-C1C)**2
      A2PC=SQRT(A2PC2)
      COSA1C=(A2C-A1C)/A2PC
      COSB1C=(B2C-B1C)/A2PC
      COSG1C=(C2C-C1C)/A2PC
      COSA2C=COSB3C*COSG1C-COSB1C*COSG3C
      COSB2C=COSA1C*COSG3C-COSA3C*COSG1C
      COSG2C=COSA3C*COSB1C-COSA1C*COSB3C
      A3PC=(A3C-A1C)*COSA1C+(B3C-B1C)*COSB1C+(C3C-C1C)*COSG1C
      B3PC=(A3C-A1C)*COSA2C+(B3C-B1C)*COSB2C+(C3C-C1C)*COSG2C
      XPC=(AT-A1C)*COSA1C+(BT-B1C)*COSB1C+(ZF(MM)-C1C)*COSG1C
      YPC=(AT-A1C)*COSA2C+(BT-B1C)*COSB2C+(ZF(MM)-C1C)*COSG2C
      ZPC=(AT-A1C)*COSA3C+(BT-B1C)*COSB3C+(ZF(MM)-C1C)*COSG3C
      R12=(XPC**2)+(YPC**2)+(ZPC**2)
      R22=(XPC-A2PC)**2+(YPC**2)+(ZPC**2)
      R32=(XPC-A3PC)**2+(YPC-B3PC)**2+(ZPC**2)
      XP=(R12-R22+(A2P**2))/(2.*A2P)
      YP=(R12-R32+(A3P**2)+(B3P**2)-(2.*A3P*XP))/(2.*B3P)
      ZP2=R12-(XP**2)-(YP**2)
      IF((R12-(XP**2)-(YP**2)).LT.0.) GO TO 100
      GO TO 110
  100 ZP2=(XP**2)+(YP**2)-R12
      ZP=-SQRT(ZP2)
      GO TO 120
```

Figure 9. Static simulation computer program

```
      PROGRAM BEACON(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
      DIMENSION ZE(3),VTERM(3),SIGB(6),RHO(100),RND(900),BS(16),BBS(16)
      READ(5,1)  (ZE(I),I=1,3)
      READ(5,1)  (VTERM(I),I=1,3)
      READ(5,2)  (SIGB(I),I=1,6)
      READ(5,3)  (BS(I),I=1,16)
      READ(5,4)  RX,RY,C1,C2,C3,CT
      DO 40 I=1,16
   40 BBS(I)=BS(I)*1000.
      DO 60 NN=1,3
      DO 60 MM=1,3
      DO 60 LL=1,6
      WRITE(6,5)  RX,RY,SIGB(LL),ZE(MM),VTERM(NN)
      DO 60 II=1,16
      A1=RX
      B1=RY
      A2=RX+BBS(II)
      B2=RY
      A3=RX
      B3=RY+BBS(II)
      AT=A1+0.5*BBS(II)
      AAT=AT/1000.
      BT=B1+0.5*BBS(II)
      BBT=BT/1000.
      A=(B2-B1)*(C3-C1)-(B3-B1)*(C2-C1)
      B=(A2-A1)*(C2-C1)-(A2-A1)*(C3-C1)
      C=(A2-A1)*(B3-B1)-(A3-A1)*(B2-B1)
      F2=A**2+B**2+C**2
      F=SQRT(F2)
      COSA3=A/F
      COSB3=B/F
      COSG3=C/F
      A2P2=(A2-A1)**2+(B2-B1)**2+(C2-C1)**2
      A2P=SQRT(A2P2)
      COSA1=(A2-A1)/A2P
      COSB1=(B2-B1)/A2P
      COSG1=(C2-C1)/A2P
      COSA2=COSB3*COSG1-COSB1*COSG3
      COSB2=COSA1*COSG3-COSA3*COSG1
      COSG2=COSA3*COSB1-COSA1*COSB3
      A3P=(A3-A1)*COSA1+(B3-B1)*COSB1+(C3-C1)*COSG1
      B3P=(A3-A1)*COSA2+(B3-B1)*COSB2+(C3-C1)*COSG2
      DO 10 I=1,900
   10 CALL NRAND(100.9,I,0.0,1.0,1,RND,0)
```

Figure 9. (continued)

```
110 ZP=SQRT(ZP2)
120 X=A1+(XP*COSA1)+(YP*COSA2)+(ZP*COSA3)
    Y=B1+(XP*COSB1)+(YP*COSB2)+(ZP*COSB3)
    Z=C1+(XP*COSG1)+(YP*COGB2)+(ZP*COSG3)
    XDOT=VTERM(NN)*((A2PC/A2P)*COSA1*COSG1C+(B3PC/B3P)*COSA2*COSG2C
   1+(A3PC-(A3P*A2PC/A2P))/B3P*COSA2*COSG1C+COSA3*COSG3C)
    YDOT=VTERM(NN)*((A2PC/A2P)*COSB1*COSG1C+(B3PC/B3P)*COSB2*COSG2C
   1+(A3PC-(A3P*A2PC/A2P))/B3P*COSB2*COSG1C+COSB3*COSG3C)
    IF(ZF(MM).EQ.0.) GO TO 50
    TTI=ZF(MM)/VTERM(NN)
    XI=X+(TTI*XDOT)
    YI=Y+(TTI*YDOT)
    GO TO 70
 50 XI=X
    YI=Y
 70 K=K+1
    RHO2=(XI-AT)**2+(YI-BT)**2
    RHO(K)=SQRT(RHO2)
 20 SUM=SUM+RHO(K)
    XBAR=SUM/10 .
    SSUM=0.
    DO 30 K=1,10
 30 SSUM=SSUM+(RHO(K)-XBAR)**2
    VAR=SSUM/90.
    STDEV=SQRT(VAR)
    RTCEP=0.944*XBAR
    WRITE(6,6) RS(II),AAT,BBT,XBAR,STDEV,RTCEP
 60 CONTINUE
  1 FORMAT(3(F5.0))
  2 FORMAT(6(F2.0))
  3 FORMAT(16(F3.0))
  4 FORMAT(2(F4.0),4(F5.0))
  5 FORMAT(1H1,4X,4HBX= ,F7.0,5X,4HBY= ,F7.0,5X,6HSIGP= ,F4.0,
   15X,12HCUTOFF ALT= ,F6.0,5X,10HTERM VEL= ,F6.0,///,
   22X,2HBS,7X,2HAT,7X,2HBT,8X,10HMEAN ERROR,6X,18HSTANDARD DEVIATION,
   35X,13HRHO AT TARGET,/,1X,4H(KM),5X,4H(KM),5X,4H(KM),11X,3H(M),
   417X,3H(M),16X,5H(CEP),/,1X,82(1H*),//)
  6 FORMAT(1X,F4.0,4X,F5.1,4X,F5.1,5X,F15.11,5X,F15.11,5X,F15.11)
    STOP
    END
00000000000000000000
NRAND
```

Figure 9. (continued)

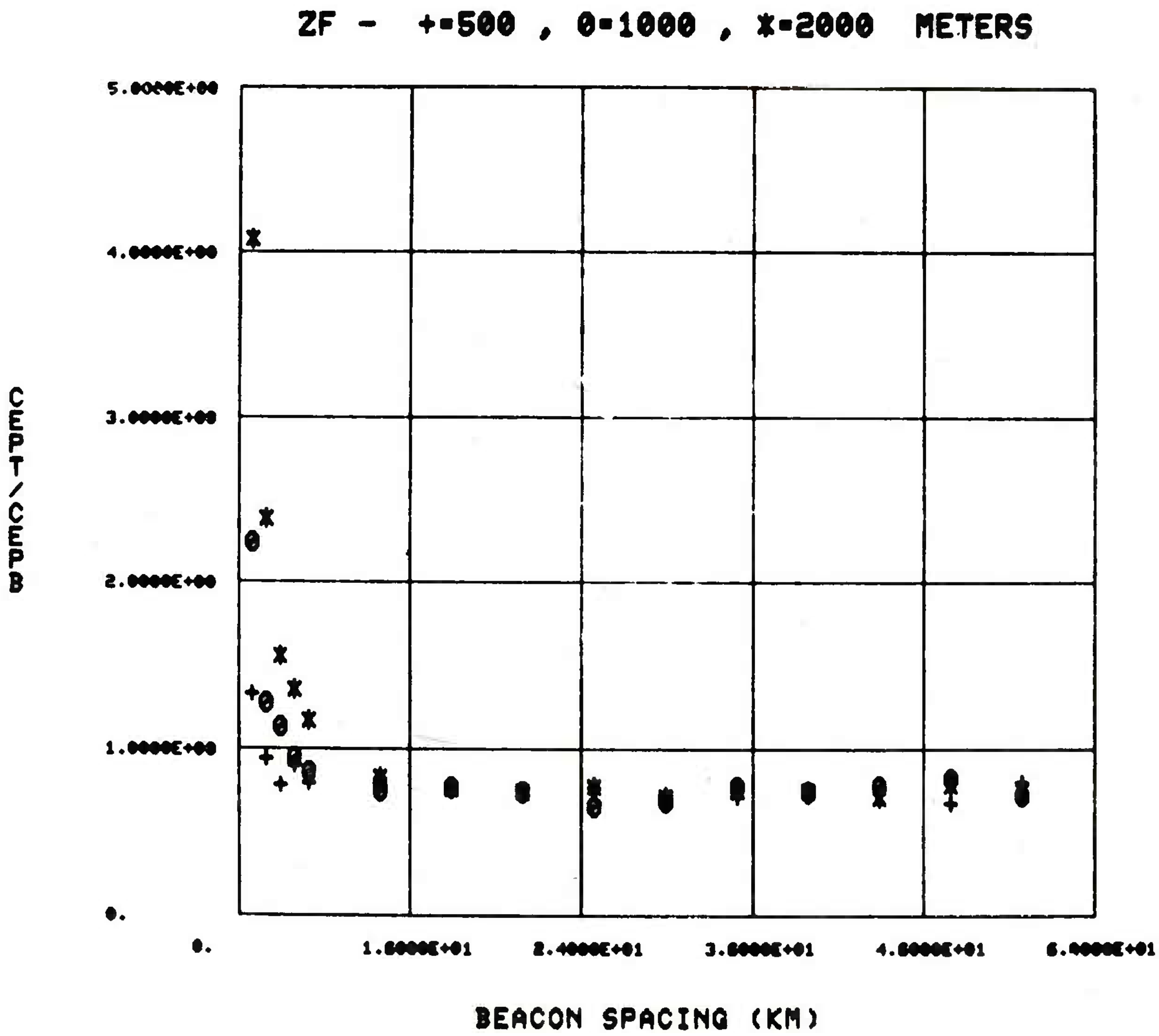

Figure 10. Ratio of CEP's as a function of beacon spacing and guidance cut-off altitude

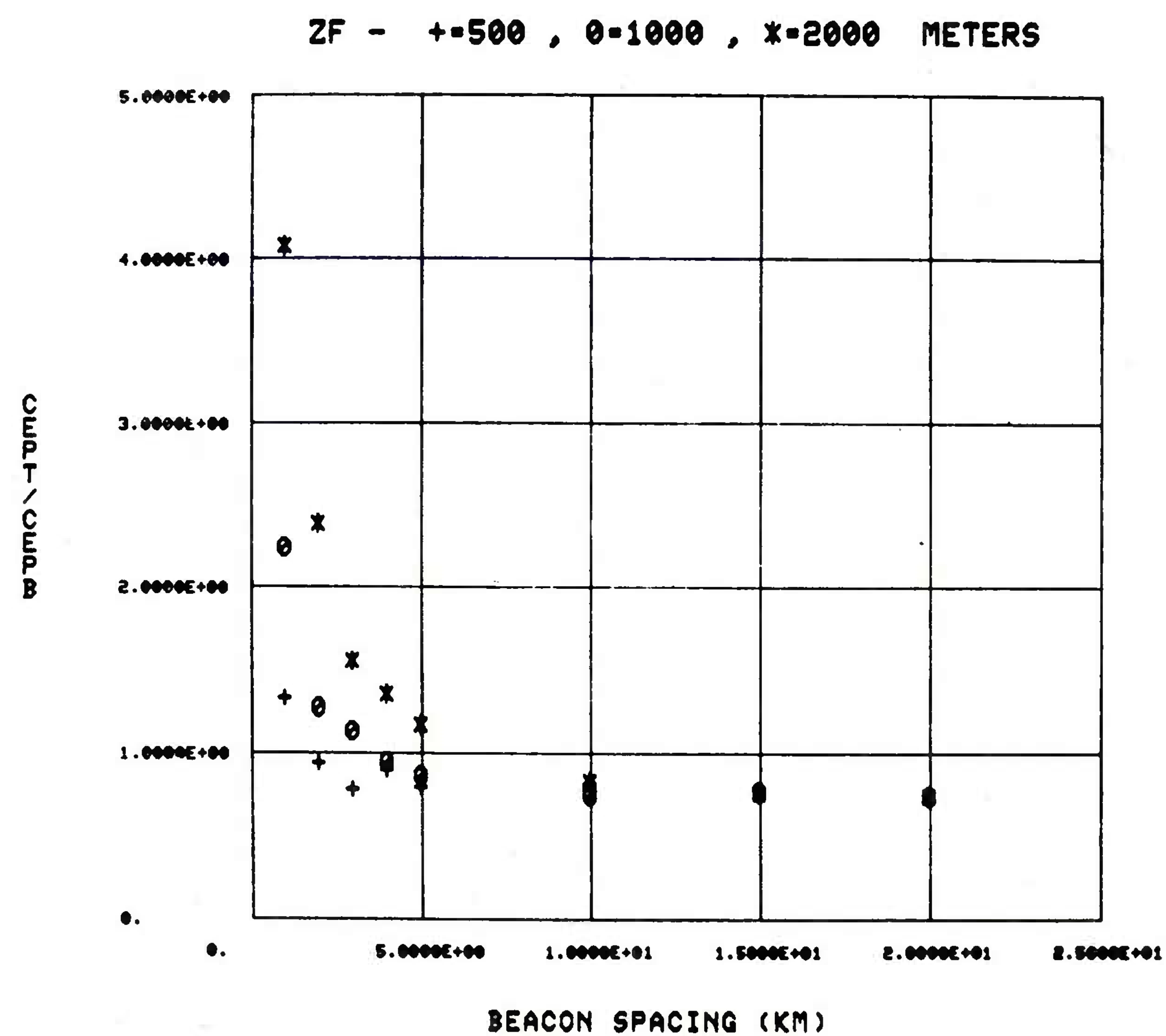

Figure 11. Ratio of CEP's as a function of beacon spacing and guidance cut-off altitude

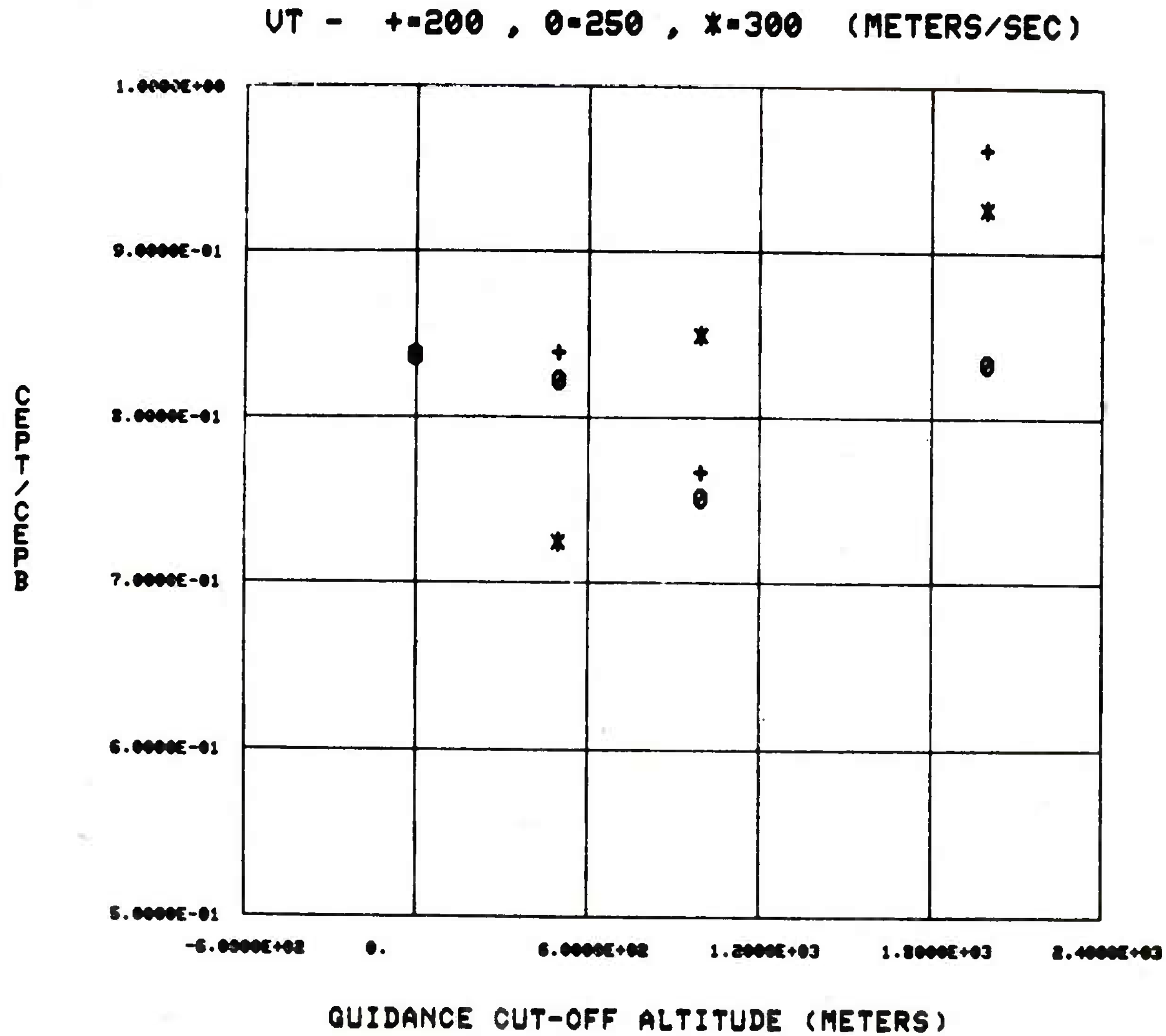

Figure 12. Ratio of CEP's as a function of guidance cut-off altitude and terminal velocity

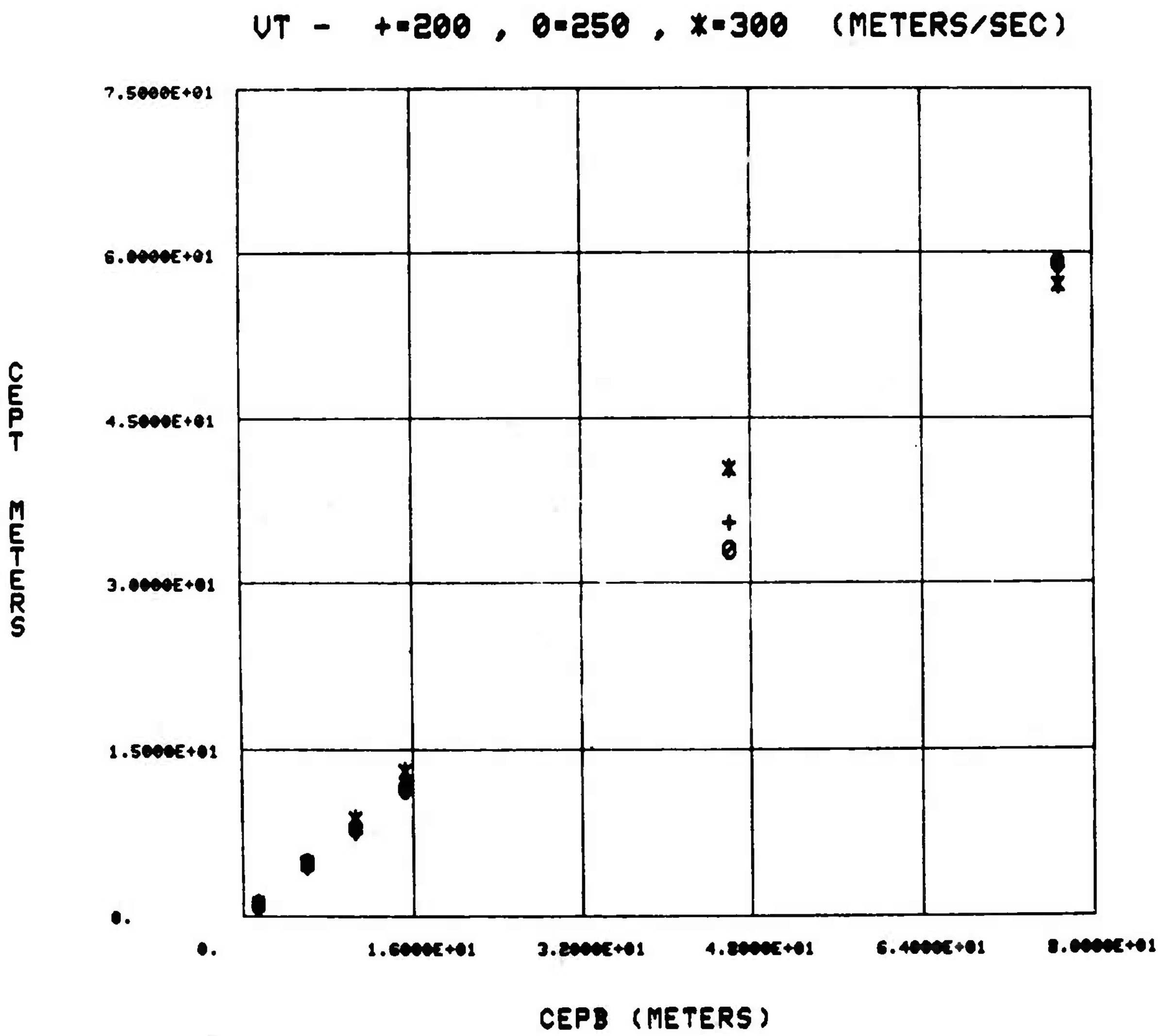

Figure 13. CEP at the target as a function of beacon CEP and terminal velocity

```
PROGRAM BEACON
ARRAY P(2),Q(2)
CONSTANT VO=555.2, QE=824.9, AZ=800.0, A=0.0188692, XMASS=54.63....
         AT=9899.5     ,BT=9899.5     ,CT=0.0       ....
         A1=7399.5     ,A2=12399.5    ,A3=7399.5    ....
         B1=7399.5     ,B2=7399.5     ,B3=12399.5   ....
         C1=0.0        ,C2=0.0        ,C3=0.0       ....
         SIGMA=5.0     ,PSIG=25.0     ....
         P=0.6875,0.0625, Q=1.,1.
CINTERVAL CI=0.5
INITIAL
PROCEDURAL(IA=) $ INTEGER IA $ END $ CALL GAUST(IA)
GQE=(QE*360.)/(6400.*57.29578)$AAZ=(AZ*360.)/(6400.*57.29578)
XI=VO*COS(GQE)*COS(AAZ)$YI=VO*COS(QQE)*SIN(AAZ)$ZI=VO*SIN(QQE)
A1C=A1+SIGMA*GAUSS(0.,1.) $ A2C=A2+SIGMA*GAUSS(0.,1.)
A3C=A3+SIGMA*GAUSS(0.,1.) $ B1C=B1+SIGMA*GAUSS(0.,1.)
B2C=B2+SIGMA*GAUSS(0.,1.) $ B3C=B3+SIGMA*GAUSS(0.,1.)
C1C=C1+SIGMA*GAUSS(0.,1.) $ C2C=C2+SIGMA*GAUSS(0.,1.)
C3C=C3+SIGMA*GAUSS(0.,1.) $ ATC=AT+SIGMA*GAUSS(0.,1.)
BTC=BT+SIGMA*GAUSS(0.,1.) $ CTC=CT+SIGMA*GAUSS(0.,1.)
D=(B2-B1)*(C3-C1)-(B3-B1)*(C2-C1)$B=(A2-A1)*(C2-C1)-(A2-A1)*(C3-C1)
C=(A2-A1)*(B3-B1)-(A3-A1)*(B2-B1)$F2=(D**2+B**2+C**2) $ F=SQRT(F2)
COSA3=D/E$COSB3=B/E$COSG3=C/E
A2P2=((A2-A1)**2+(B2-B1)**2+(C2-C1)**2)$A2P=SQRT(A2P2)
COSA1=(A2-A1)/A2P$COSB1=(B2-B1)/A2P$COSG1=(C2-C1)/A2P
A3P=(A3-A1)*COSA1+(B3-B1)*COSB1+(C3-C1)*COSG1
COSA2=COSB3*COSG1-COSB1*COSG3$COSB2=COSA1*COSG3-COSA3*COSG1
COSG2=COSA3*COSB1-COSA1*COSB3
B3P=(A3-A1)*COSA2+(B3-B1)*COSB2+(C3-C1)*COSG2
AC=(B2C-B1C)*(C3C-C1C)-(B3C-B1C)*(C2C-CTC)
BC=(A2C-A1C)*(C2C-C1C)-(A2C-A1C)*(C3C-C1C)
CC=(A2C-A1C)*(B3C-B1C)-(A3C-A1C)*(B2C-B1C)
FC2=((AC**2)+(BC**2)+(CC**2))$FC=SQRT(FC2)
```

Figure 14. Dynamic simulation computer program

```
COSA3C=AC/FC$COSB3C=BC/FC$COSG3C=CC/FC
A2PC2=((A2C-A1C)**2+(B2C-B1C)**2+(C2C-C1C)**2)$A2PC=SQRT(A2PC2)
COSA1C=(A2C-A1C)/A2PC$COSB1C=(B2C-B1C)/A2PC$COSG1C=(C2C-C1C)/A2PC
COSA2C=COSB3C*COSG1C-COSB1C*COSG3C$COSB2C=COSA1C*COSG3C-COSA3C*COSG1C
COSG2C=COSA3C*COSB1C-COSA1C*COSB3C
A3PC=(A3C-A1C)*COSA1C+(B3C-B1C)*COSB1C+(C3C-C1C)*COSG1C
B3PC=(A3C-A1C)*COSA2C+(B3C-B1C)*COSB2C+(C3C-C1C)*COSG2C
END
DYNAMIC
TERMT(T.GT.5.0.AND.Z.LE.-20.0)
DERIVATIVE CALC
NSTEPS IZ=4 $ ALGORITHM IX=5 , IY=5
TABLE RHO,1,90,0.,100.,200.,300.,400.,500.,600.,700.,800.,900.....
1000.,1100.,1200.,1300.,1400.,1500.,1600.,1700.,1800.,1900.,2000.....
2100.,2200.,2300.,2400.,2500.,2600.,2700.,2800.,2900.,3000.,3100.....
3200.,3300.,3400.,3500.,3600.,3700.,3800.,3900.,4000.,4100.,4200.....
4300.,4400.,4500.,4600.,4700.,4800.,4900.,5000.,5100.,5200.,5300.....
5400.,5500.,5600.,5700.,5800.,5900.,6000.,6100.,6200.,6300.,6400.....
6500.,6600.,6700.,6800.,6900.,7000.,7100.,7200.,7300.,7400.,7500.....
7600.,7700.,7800.,7900.,8000.,8100.,8200.,8300.,8400.,8500.,8600.....
8700.,8800.,8900.....
1.2250,1.2133,1.2017,1.1901,1.1786,1.1673,1.1560,1.1448,1.1337....
1.1226,1.1117,1.1008,1.0900,1.0793,1.0687,1.0581,1.0476,1.0372....
1.0269,1.0167,1.0066,0.99648,0.98648,0.97656,0.96672,0.95695,...
0.94726,0.93765,0.92811,0.91864,0.90925,0.89994,0.89069,0.88152,...
0.87243,0.86340,0.85445,0.84557,0.83676,0.82802,0.81935,0.81075....
0.80222,0.79376,0.78536,0.77704,0.76878,0.76059,0.75247,0.74442,...
0.73643,0.72851,0.72065,0.71286,0.70513,0.69747,0.68987,0.68234,...
0.67486,0.66746,0.66011,0.65283,0.64561,0.63845,0.63135,0.62431,...
0.61733,0.61041,0.60356,0.59676,0.59002,0.58334,0.57671,0.57015,...
0.56364,0.55719,0.55080,0.54446,0.53818,0.53196,0.52579,0.51967....
0.51361,0.50761,0.50165,0.49576,0.48991,0.48412,0.47838,0.47270
VEL2=(XD**2+YD**2+ZD**2) $ VEL=SQRT(VEL2)
```

Figure 14. (continued)

```
IF(VEL.LE.340.16) CD=0.215 $ IF(VEL.GT.340.16) CD=0.397
XDD=  AX-((0.5*RHO(Z)*CD*A)/XMASS)*VEL*XD
YDD=  AY-((0.5*RHO(Z)*CD*A)/XMASS)*VEL*YD
ZDD=-(9.80665-((Z/100.)*3.0777777E-4))-((0.5*RHO(Z)*CD*A)/XMASS)*VE...
L*ZD
XD=INTEG(XDD,XI)$YD=INTEG(YDD,YI)$ZD=INTEG(ZDD,ZI)
THE=ATAN2(YD,XD) $ THETA=THE*57.29578 $ VP2=(XD**2+YD**2)
VP=SQRT(VP2) $ GAM=ATAN2(ZD,VP) $ GAMMA=GAM*57.29578 $ X=INTEG(XD,0.0)
Y=INTEG(YD,0.0) $ Z=INTEG(ZD,0.0) $ R2=(X**2+Y**2) $ R=SQRT(R2)
XP=(X-A1)*COSA1+(Y-B1)*COSB1+(Z-C1)*COSG1
YP=(X-A1)*COSA2+(Y-B1)*COSB2+(Z-C1)*COSG2
ZP=(X-A1)*COSA3+(Y-B1)*COSB3+(Z-C1)*COSG3
R12=XP**2+YP**2+ZP**2$R22=(XP-A2P)**2+YP**2+ZP**2
R32=(XP-A3P)**2+(YP-B3P)**2+ZP**2
R1=SQRT(R12) $ R2=SQRT(R22) $ R3=SQRT(R32)
G1=GAUSS(0.,1.) $ G2=GAUSS(0.,1.) $ G3=GAUSS(0.,1.)
R12C=R12+(2.*R1*RSIG*G1)+(RSIG**2)*(G1**2)
R22C=R22+(2.*R2*RSIG*G2)+(RSIG**2)*(G2**2)
R32C=R32+(2.*R3*RSIG*G3)+(RSIG**2)*(G3**2)
XPC=(1./(2.*A2PC))*(R12C-R22C+A2PC**2)
YPC=(1./(2.*B3PC))*(R12C-R32C+A3PC**2+B3PC**2-(2.*A3PC*XPC))
ZPC2=(R12-(XPC**2+YPC**2)) $ IF(ZPC2.LT.0.) ZPC2=0.0 $ ZPC=SQRT(ZPC2)
XC=A1C+(XPC*COSA1C)+(YPC*COSA2C)+(ZPC*COSA3C)
YC=B1C+(XPC*COSB1C)+(YPC*COSB2C)+(ZPC*COSB3C)
ZC=C1C+(XPC*COSG1C)+(YPC*COSG2C)+(ZPC*COSG3C)
XERR=X-AT$YERR=Y-BT$XERRC=XC-ATC$YERRC=YC-BTC
TX=TRAN(1,1,P,Q,XERRC)$TY=TRAN(1,1,P,Q,YERRC)
AX=((2.46*TX)/XMASS)*STEP(28.75,T)$AY=((2.46*TY)/XMASS)*STEP(28.75,T)
RHOZ=RHO(Z)
DEBUG T,3,60,75
END $ END $ TERMINAL $ END $ END
```

Figure 14. (continued)

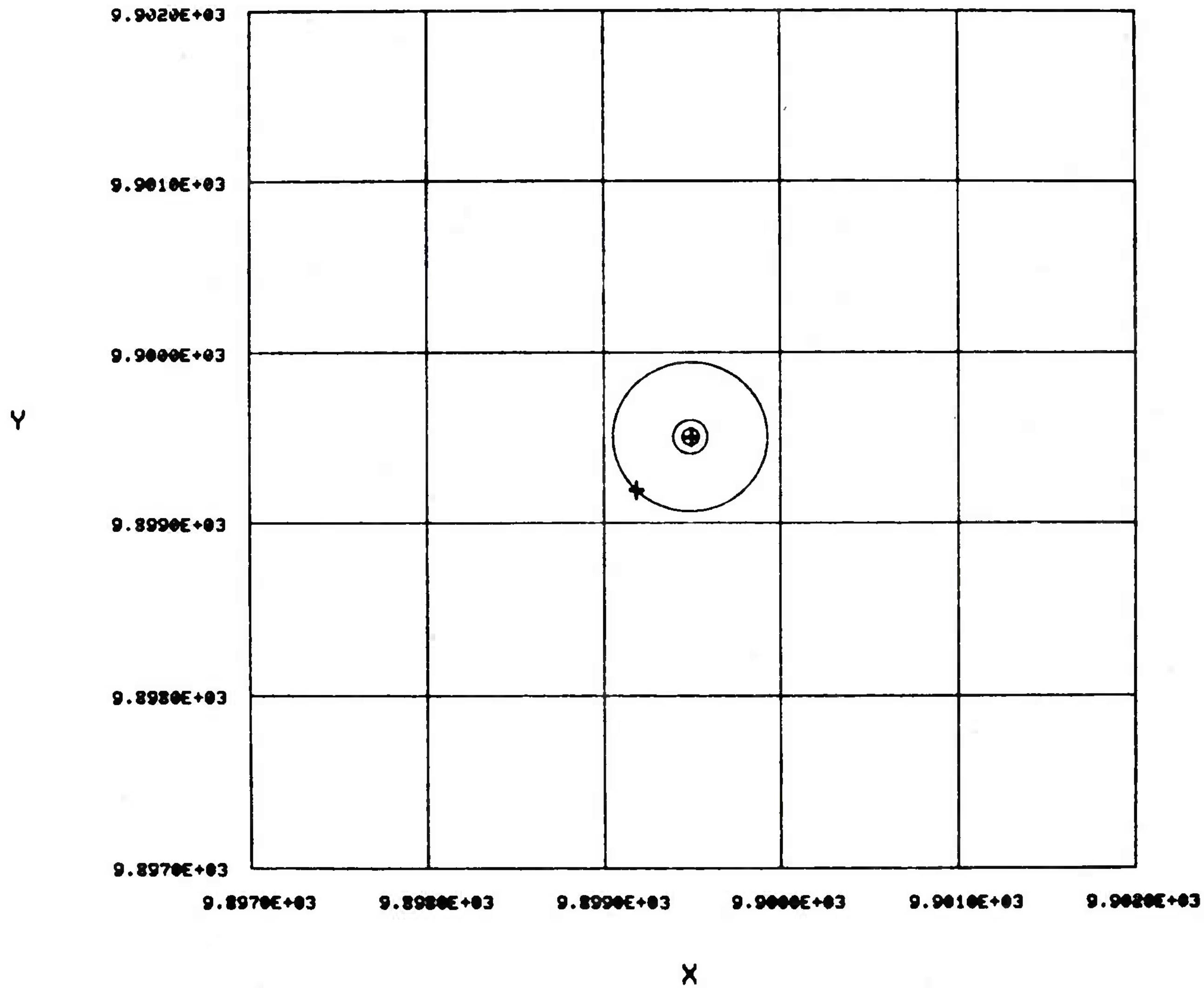

Figure 15. Plot of impact points and CEP for Case I, Geometries I and II

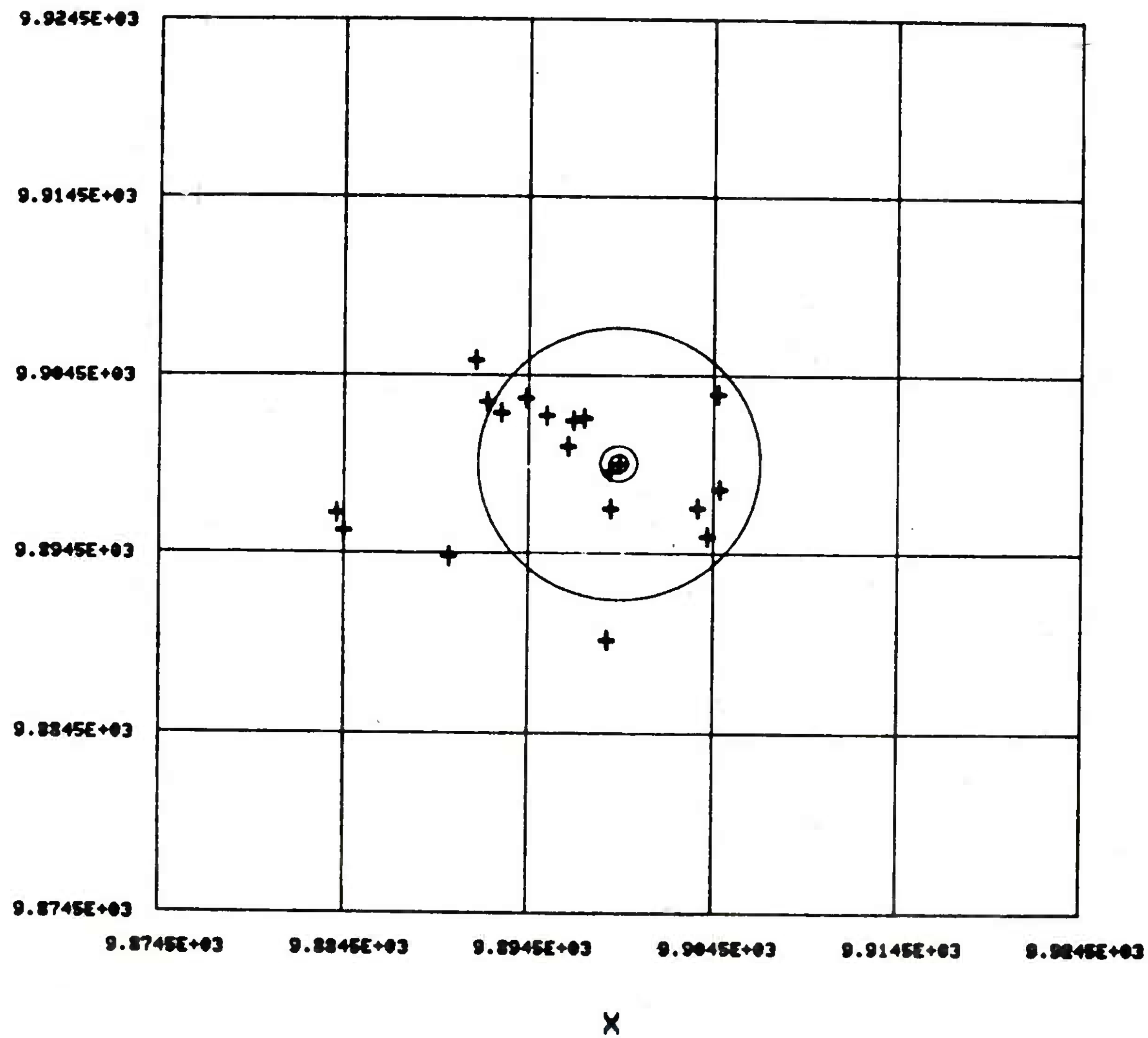

Figure 16. Plot of impact points and CEP for Case II, Geometry I

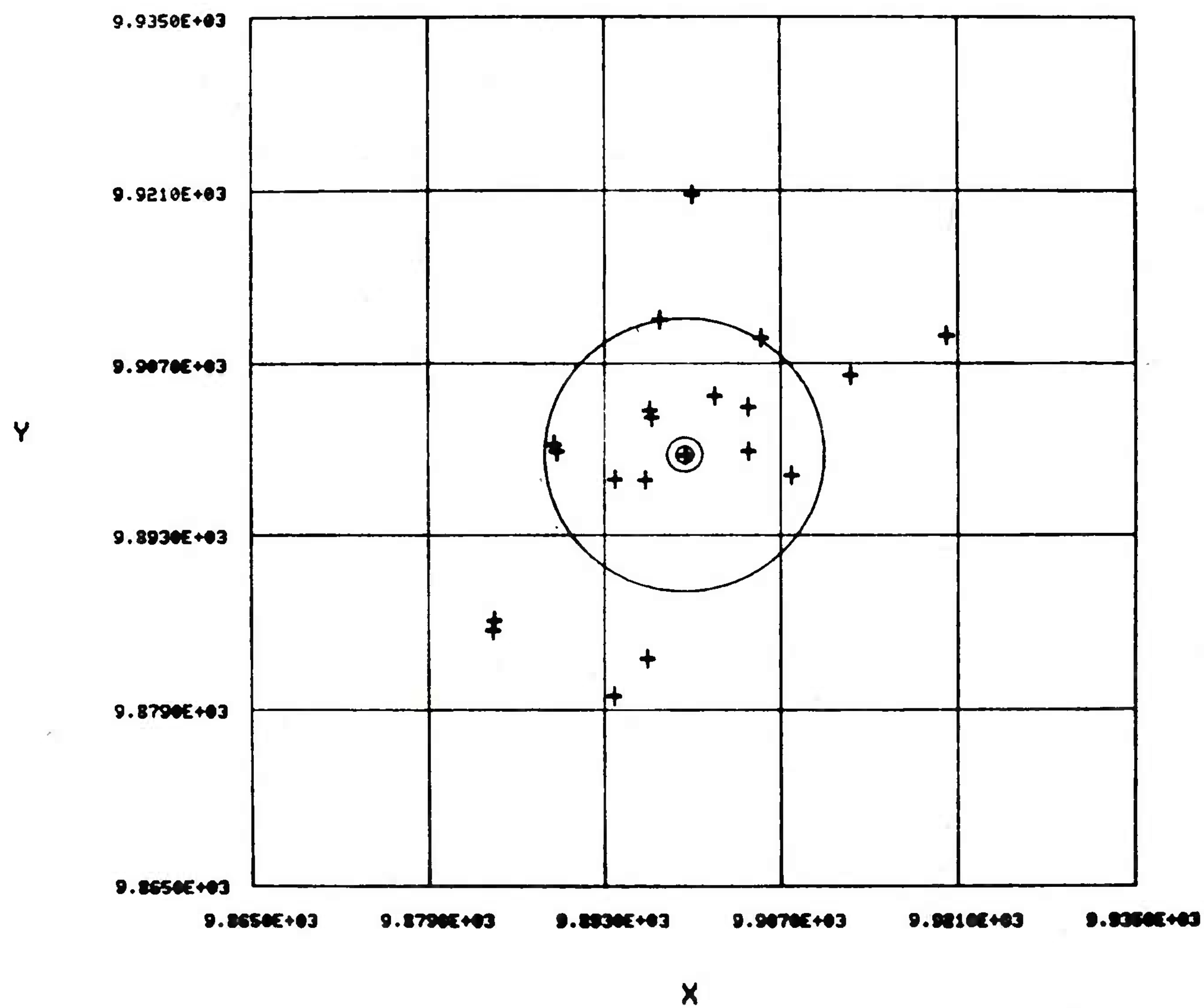

Figure 17. Plot of impact points and CEP for Case III, Geometry I

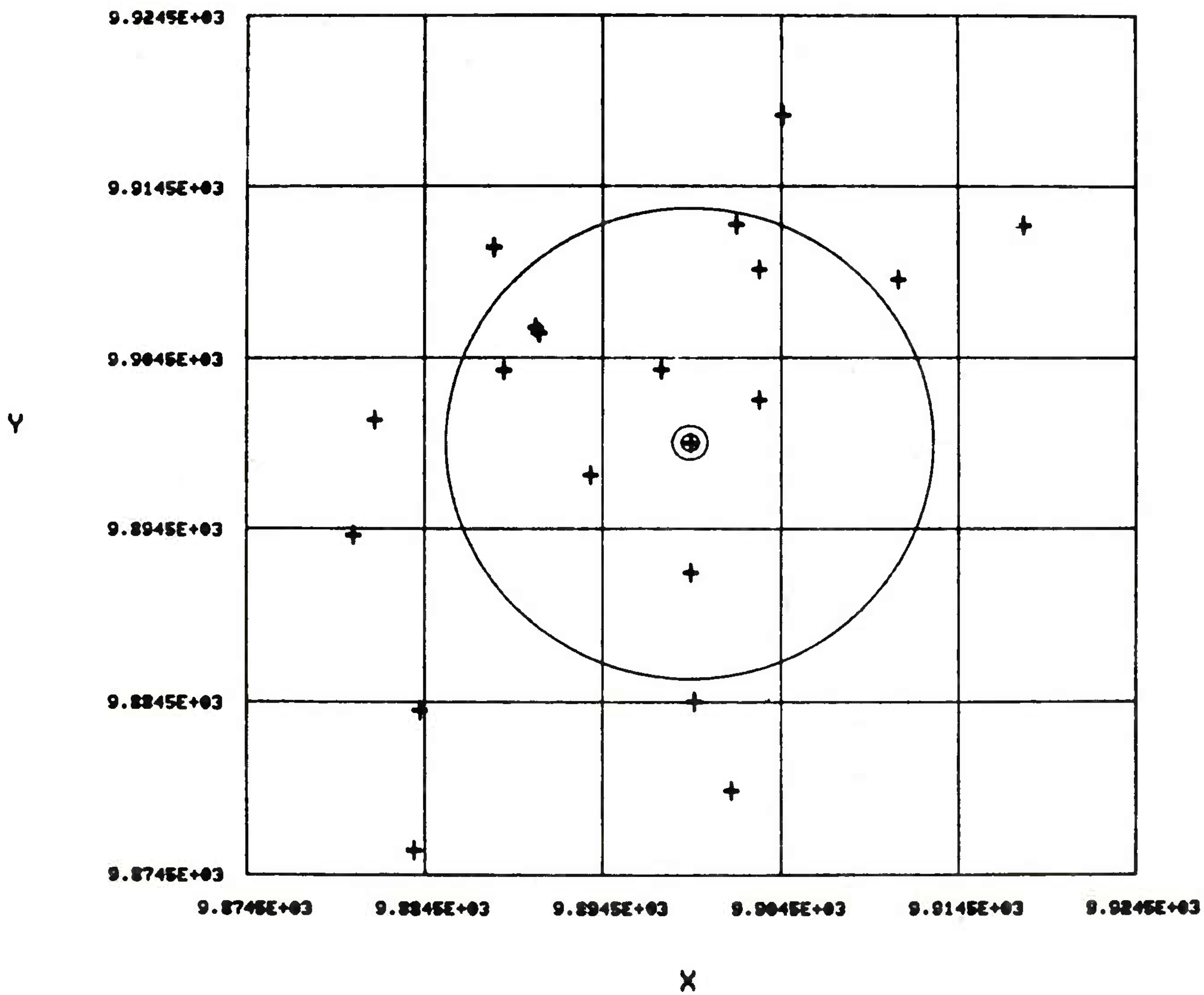

Figure 18. Plot of impact points and CEP for Case IV, Geometry I

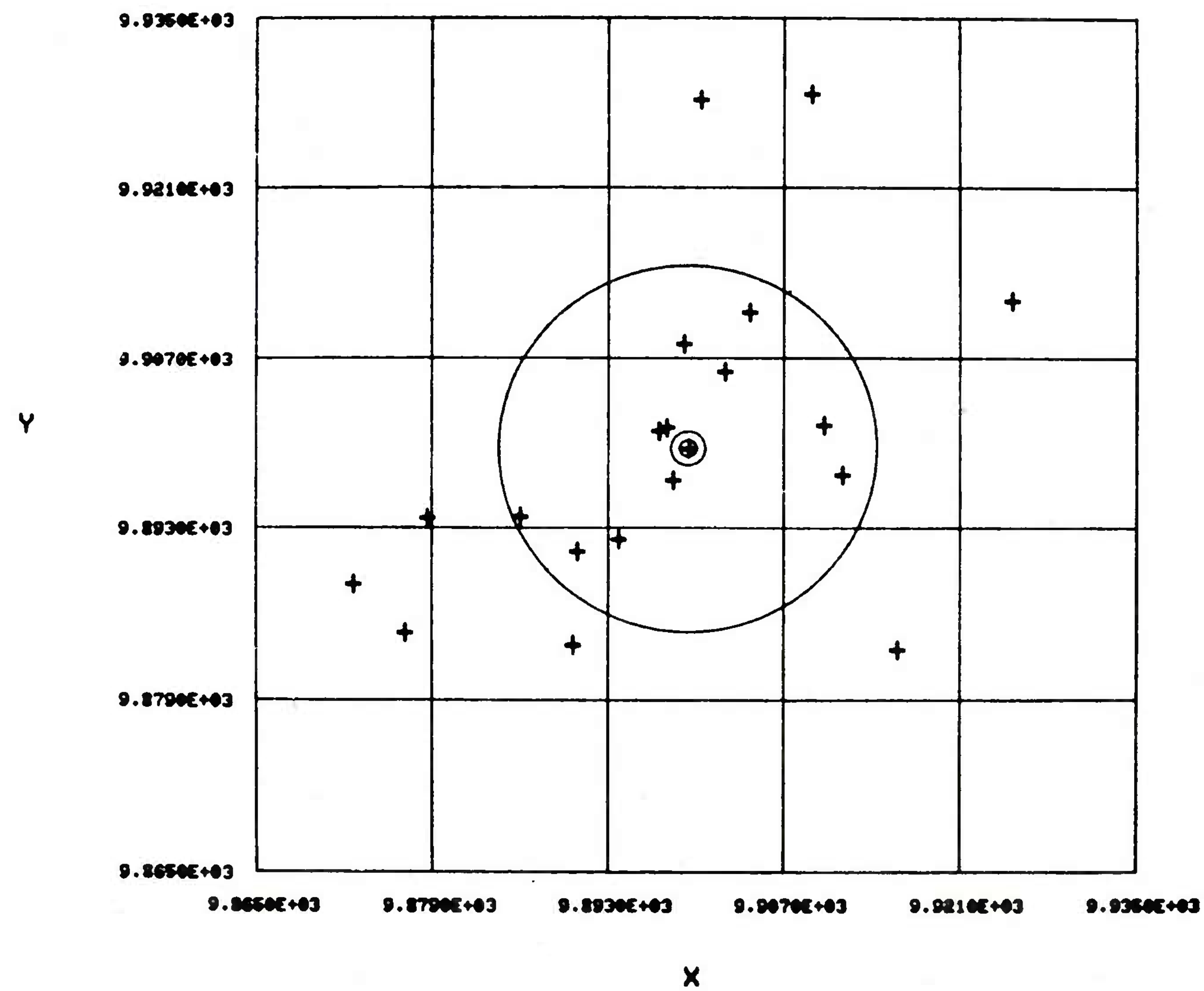

Figure 19. Plot of impact points and CEP for Case II, Geometry II

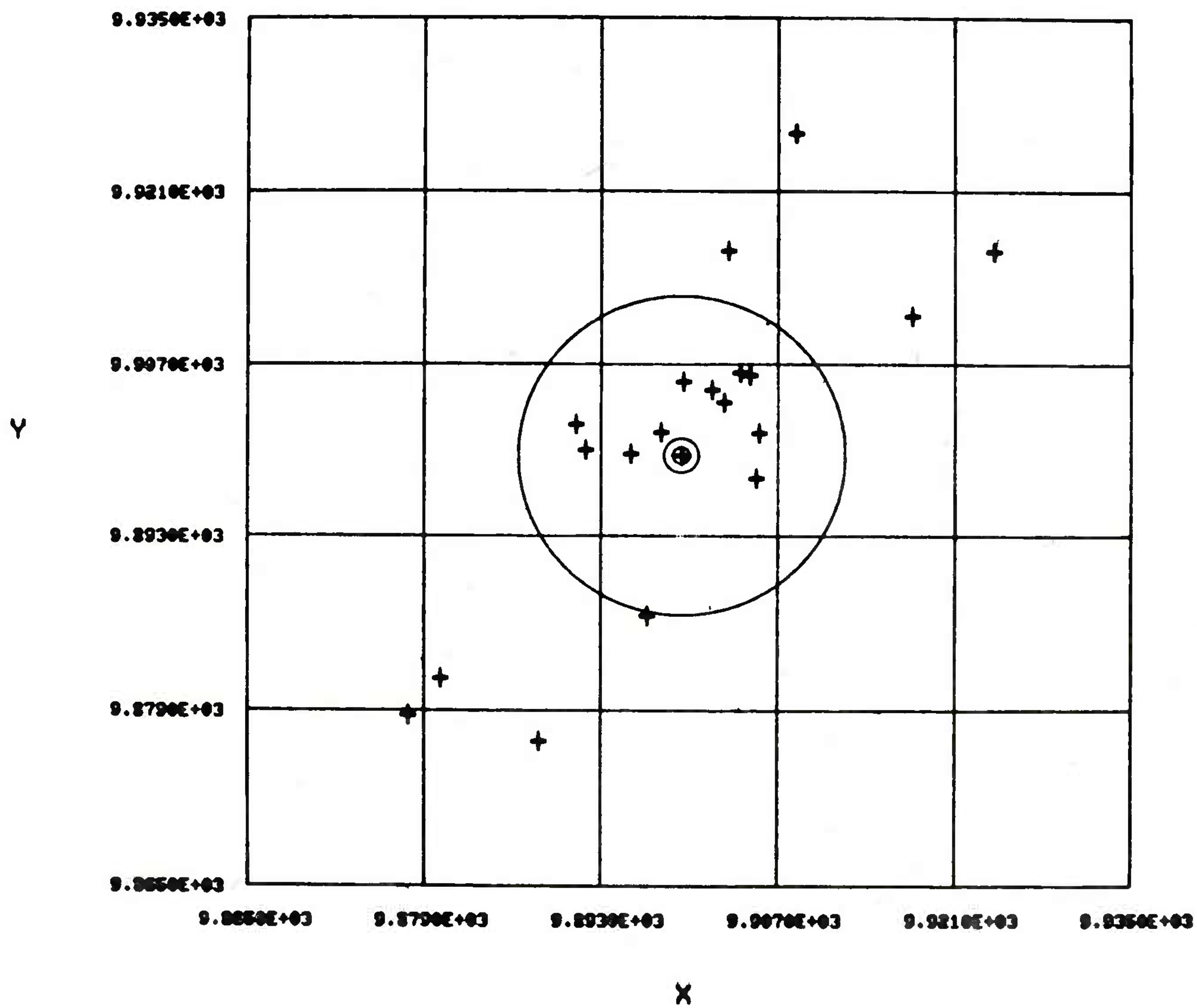

Figure 20. Plot of impact points and CEP for Case III, Geometry II

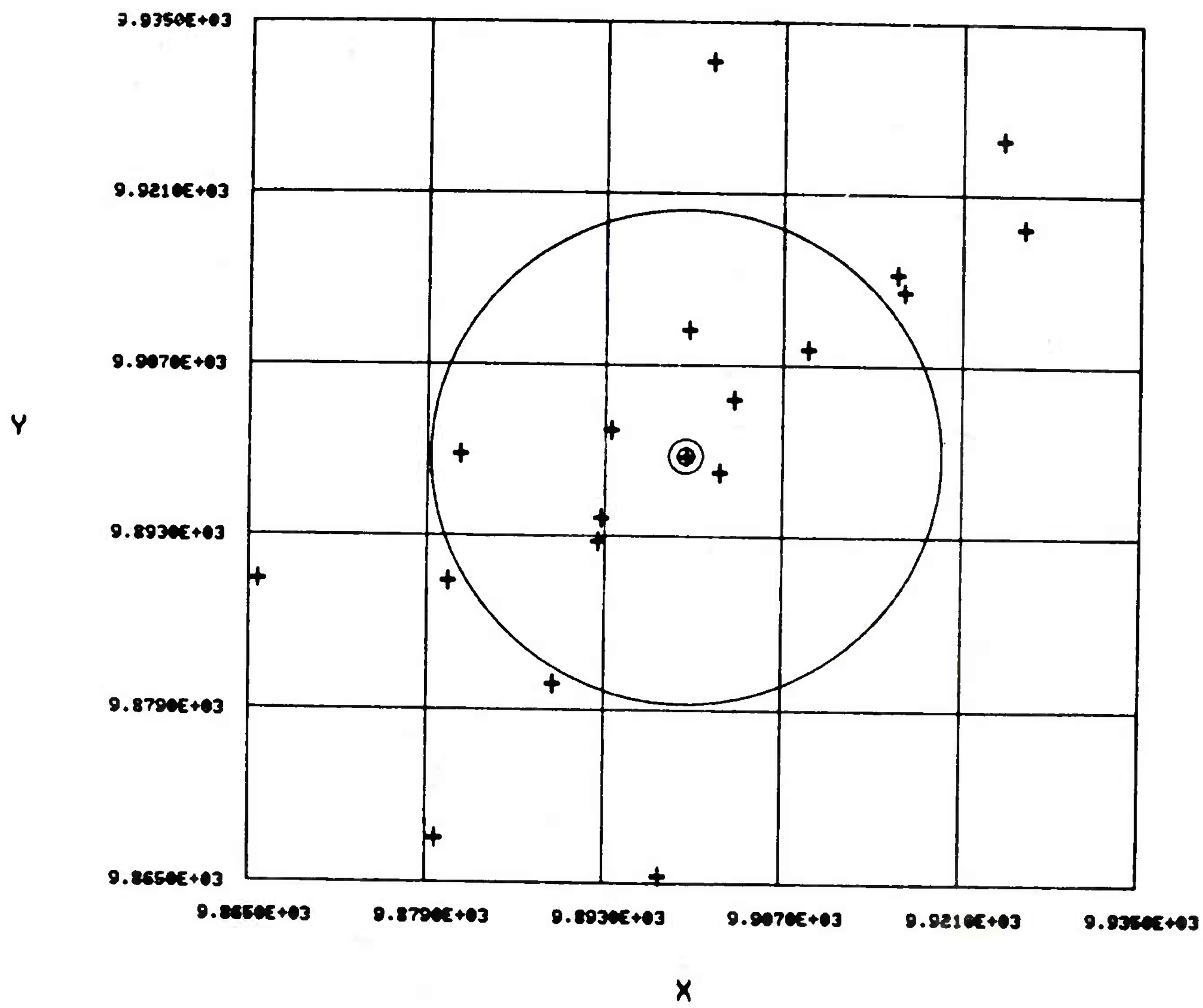

Figure 21. Plot of impact points and CEP for Case IV, Geometry II

APPENDIX A

STATIC SIMULATION RESULTS

Table A1. Static simulation results; $\sigma_B = 1$, $z_f = 0$, $V_T = 0$

RX= 15000. RY= 15000. SIGR= 1. CUTOFF ALT= 0. TERM VEL= 0.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	1.18508607898	.65829149441	1.11872125856
2.	16.0	16.0	1.34804067765	.66020247298	1.27255039970
3.	16.5	16.5	1.31478219022	.75192495527	1.24115438757
4.	17.0	17.0	1.13994257207	.64542987855	1.07610578803
5.	17.5	17.5	1.26022752626	.68642465579	1.18965478478
10.	20.0	20.0	1.24050938480	.61367660242	1.17104085925
15.	22.5	22.5	1.15249485467	.63530193214	1.08795514281
20.	25.0	25.0	1.32008380468	.78799770598	1.24615911162
25.	27.5	27.5	1.28626371646	.64889059099	1.21423294834
30.	30.0	30.0	1.20259264770	.71800315984	1.13524745943
35.	32.5	32.5	1.23369266221	.63140100019	1.16460587313
40.	35.0	35.0	1.27584778782	.73154948735	1.20440031171
45.	37.5	37.5	1.17964957706	.68519066584	1.11358920074
50.	40.0	40.0	1.27023513063	.69558676160	1.19910196331
55.	42.5	42.5	1.28761605535	.79251434004	1.21550955625
60.	45.0	45.0	1.23335267842	.62491144994	1.16334092843

Table A2. Static simulation results; $\sigma_B = 4$, $z_f = 0$, $V_T = 0$

RX= 15000. RY= 15000. SIGB= 4. CUTOFF ALT= 0. TERM VEL= 0.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	4.86548305148	2.46872771324	4.59301600060
2.	16.0	16.0	5.41614692616	3.10331071125	5.11284269829
3.	16.5	16.5	4.95360385311	2.53050071002	4.67620203733
4.	17.0	17.0	4.59516071007	2.49271432112	4.33783171031
5.	17.5	17.5	4.90237832879	2.48082605246	4.62784514238
10.	20.0	20.0	4.82308574894	3.10608033668	4.55299294700
15.	22.5	22.5	4.92281638369	2.74498493125	4.64713866621
20.	25.0	25.0	4.94508651832	2.96218385256	4.66816167329
25.	27.5	27.5	4.83084575939	2.60254068761	4.56031839687
30.	30.0	30.0	5.04087126265	3.33979645717	4.75858247194
35.	32.5	32.5	5.18593329005	2.68221205790	4.89552102581
40.	35.0	35.0	5.00579467147	2.91812668836	4.72547016987
45.	37.5	37.5	4.91148204386	2.69547122484	4.63643904940
50.	40.0	40.0	4.90583272290	3.03026379739	4.63110609042
55.	42.5	42.5	5.10094267757	2.85142193291	4.81528988763
60.	45.0	45.0	5.07923121839	2.87324885570	4.79479427016

Table A3. Static simulation results; $\sigma_B = 7$, $z_f = 0$, $V_T = 0$

RX= 15000. RY= 15000. SIGR= 7. CUTOFF ALT= 0. TERM VEL= 0.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	9.10068852093	4.92634027904	8.59104996376
2.	16.0	16.0	9.27462170475	4.86004004528	8.75524288928
3.	16.5	16.5	9.15272629749	4.85301800266	8.64017362483
4.	17.0	17.0	7.84416076058	4.64831557692	7.40488775709
5.	17.5	17.5	9.27852486406	4.35691326241	8.75892747168
10.	20.0	20.0	7.92501504573	4.30926209274	7.48121420316
15.	22.5	22.5	8.49732796889	4.87904737270	8.02147760264
20.	25.0	25.0	8.59254006784	4.16783965945	8.11135782404
25.	27.5	27.5	8.39662734232	5.09040286492	7.92641621115
30.	30.0	30.0	8.33215166655	4.93677636460	7.86555117322
35.	32.5	32.5	7.74692823448	4.67811815539	7.31310025335
40.	35.0	35.0	8.22830767780	5.19945141486	7.76752244784
45.	37.5	37.5	7.87906156969	4.24904153049	7.43783412179
50.	40.0	40.0	8.53207816750	5.08753409845	8.05428179012
55.	42.5	42.5	8.47755018038	4.91298157047	8.00280737028
60.	45.0	45.0	8.78426560493	4.90314987414	8.29234673106

Table A4. Static simulation results; $\sigma_B = 10$, $z_f = 0$, $V_T = 0$

RX= 15000. RY= 15000. SIGB= 10. CUTOFF ALT= 0. TERM VEL= 0.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	12.63533299357	6.66942880550	11.92775434593
2.	16.0	16.0	12.85058109982	7.00671981771	12.13094855823
3.	16.5	16.5	12.30364945438	6.82668479413	11.61464508493
4.	17.0	17.0	12.81935342269	7.77873409738	12.10146963162
5.	17.5	17.5	13.84551548534	6.90758313682	13.07016661816
10.	20.0	20.0	13.66866336778	8.12460124642	12.90321821919
15.	22.5	22.5	13.48194606825	8.05892310600	12.72695708843
20.	25.0	25.0	12.02639174109	6.85144200716	11.35291380359
25.	27.5	27.5	13.09814292671	6.54872699820	12.36464692281
30.	30.0	30.0	11.53805946073	6.60987172856	10.89192813093
35.	32.5	32.5	13.06175271937	7.26397424711	12.33029456709
40.	35.0	35.0	11.96477567714	6.08920964703	11.29474823922
45.	37.5	37.5	13.21973304225	7.47785561608	12.47942799189
50.	40.0	40.0	11.11366709093	7.06054711340	10.49130173384
55.	42.5	42.5	13.75676283527	7.79270975553	12.98638411649
60.	45.0	45.0	12.93415989560	7.09349983128	12.20984694145

Table A5. Static simulation results; $\sigma_B = 30$, $z_f = 0$, $V_T = 0$

RX= 15000. RY= 15000. SIGB= 30. CUTOFF ALT= 0. TERM VEL= 0.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	34.45595456235	17.88235341797	32.52642110686
2.	16.0	16.0	38.30377685508	20.62233987305	36.15876535120
3.	16.5	16.5	34.93947428268	19.78810039138	32.98286372285
4.	17.0	17.0	35.05605448327	21.45795085364	33.09291543221
5.	17.5	17.5	38.46709930879	20.38158490477	36.31294174750
10.	20.0	20.0	38.15204966513	22.22237165553	36.01553488388
15.	22.5	22.5	37.84582052912	20.60817981489	35.72645457948
20.	25.0	25.0	33.26545329630	18.61906509719	31.40258791170
25.	27.5	27.5	38.02144877399	21.11789006481	35.89224764265
30.	30.0	30.0	38.06707755201	24.76825489080	35.93532120910
35.	32.5	32.5	37.00847045627	21.57773110440	34.93599611072
40.	35.0	35.0	37.72468290520	22.55515731799	35.61210066251
45.	37.5	37.5	34.02328269234	20.23899971122	32.11797886157
50.	40.0	40.0	36.03446669170	18.81269280158	34.01653655697
55.	42.5	42.5	38.99274273392	20.22241923295	36.80914914082
60.	45.0	45.0	38.12668838805	18.18818605772	35.99159383832

Table A6. Static simulation results; $\sigma_B = 50$, $z_f = 0$, $V_T = 0$

RX= 15000. RY= 15000. SIGB= 50. CUTOFF ALT= 0. TERM VEL= 0.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	57.05774000410	31.92741455468	53.86250656387
2.	16.0	16.0	63.81639398959	34.40507855520	60.24267592617
3.	16.5	16.5	57.89814491196	32.35789810183	54.65584879689
4.	17.0	17.0	62.38277886366	35.12189194897	58.88934324730
5.	17.5	17.5	63.86535105306	37.36555641575	60.28889139409
10.	20.0	20.0	62.02539139884	34.55911212975	58.55196948051
15.	22.5	22.5	60.30519407700	31.26358371002	56.92810320868
20.	25.0	25.0	59.10008430006	33.49910760547	55.79047957925
25.	27.5	27.5	64.80447382821	36.68277984656	61.17542329383
30.	30.0	30.0	57.52274729221	30.43589909450	54.30147344384
35.	32.5	32.5	57.27036213368	33.18477511218	54.06322185420
40.	35.0	35.0	64.55077425637	38.62564774916	60.93593089802
45.	37.5	37.5	63.04547243243	36.91430290728	59.51492597622
50.	40.0	40.0	57.22666113645	29.45861532102	54.02196811281
55.	42.5	42.5	64.97997312499	38.57990435908	61.34109462999
60.	45.0	45.0	63.33674285328	38.83072740424	59.78988525350

Table A7. Static simulation results; $\sigma_B = 1$, $z_f = 500$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 1. CUTOFF ALT= 500. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	2.07007267568	.91688568716	1.95414860585
2.	16.0	16.0	1.51192512836	.87549642094	1.42725732117
3.	16.5	16.5	1.39986900573	.74351982670	1.32147634141
4.	17.0	17.0	1.13045816970	.65054228037	1.06715251219
5.	17.5	17.5	1.28700675202	.70239133045	1.21493437391
10.	20.0	20.0	1.26289637729	.64153952864	1.19217418016
15.	22.5	22.5	1.16921067175	.63903950177	1.10373487413
20.	25.0	25.0	1.32388368343	.79033010149	1.24974619716
25.	27.5	27.5	1.28438911831	.64792618841	1.21246332768
30.	30.0	30.0	1.20001017324	.72028947050	1.13280960354
35.	32.5	32.5	1.23506150797	.62439074742	1.16589806353
40.	35.0	35.0	1.28206234486	.73155754831	1.21026685354
45.	37.5	37.5	1.18157388457	.69037870668	1.11540574703
50.	40.0	40.0	1.27089441621	.69724397470	1.19972432890
55.	42.5	42.5	1.29106303446	.79038062204	1.21876350453
60.	45.0	45.0	1.23086313160	.62468934918	1.16193479623

Table A8. Static simulation results; $\sigma_B = 4$, $z_f = 500$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 4. CUTOFF ALT= 500. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	8.16445226663	4.07336935439	7.70724293970
2.	16.0	16.0	6.42098873601	3.56245188179	6.06141336679
3.	16.5	16.5	5.25688752305	2.88402458805	4.96250182176
4.	17.0	17.0	4.95228566676	2.82962864982	4.67495766942
5.	17.5	17.5	5.04313949297	2.51975337447	4.76072368136
10.	20.0	20.0	4.95701507100	3.10378587426	4.67942222703
15.	22.5	22.5	4.96293646311	2.75947909828	4.68501202118
20.	25.0	25.0	4.93281302257	2.99601135179	4.65657549331
25.	27.5	27.5	4.87486479456	2.64091572759	4.60187236606
30.	30.0	30.0	5.03810590726	3.36208719986	4.75597197645
35.	32.5	32.5	5.19619242042	2.69576823860	4.90520564488
40.	35.0	35.0	5.01143597607	2.92937115215	4.73079556141
45.	37.5	37.5	4.89809809661	2.68566378973	4.62380460320
50.	40.0	40.0	4.90404969175	3.02217565523	4.62942290902
55.	42.5	42.5	5.09744761125	2.84967374062	4.81199054502
60.	45.0	45.0	5.07820883965	2.88491600570	4.79382914463

Table A9. Static simulation results; $\sigma_B = 7$, $z_f = 500$, $V_T = 200$

DX= 15000. DY= 15000. SIGB= 7. CUTOFF ALT= 500. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	15.81660421820	8.09349124951	14.93187438198
2.	16.0	16.0	11.15556874711	5.65749758782	10.53085689727
3.	16.5	16.5	10.58834095116	5.72781932246	9.99539385789
4.	17.0	17.0	8.62456094782	4.68792347489	8.14158553475
5.	17.5	17.5	9.27466834897	4.40910997359	8.75528692143
10.	20.0	20.0	8.10562309671	4.32899404615	7.65170820329
15.	22.5	22.5	8.55726049387	4.91888603106	8.07805390622
20.	25.0	25.0	8.62931270989	4.21452859278	8.14607119814
25.	27.5	27.5	8.41920389897	5.17320797641	7.94772848063
30.	30.0	30.0	8.35597060550	4.94442646096	7.88803625159
35.	32.5	32.5	7.71073707664	4.71741794008	7.27893580035
40.	35.0	35.0	8.23096909993	5.20054324241	7.77003483033
45.	37.5	37.5	7.89796923042	4.24719568084	7.45568295352
50.	40.0	40.0	8.58044432979	5.10291536496	8.09993944732
55.	42.5	42.5	8.50394454406	4.90333636583	8.02772364959
60.	45.0	45.0	8.81483097050	4.87418084634	8.32120043615

Table A10. Static simulation results; $\sigma_B = 10$, $z_f = 500$, $V_T = 200$

PX= 15000. PY= 15000. SIGB= 10. CUTOFF ALT= 500. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	22.04151861906	11.89827042625	20.80719357639
2.	16.0	16.0	15.64736152774	8.34573927990	14.77110928219
3.	16.5	16.5	14.14645322544	7.17265347048	13.35425184482
4.	17.0	17.0	14.04986337364	7.73596268016	13.26307102471
5.	17.5	17.5	14.60232275940	6.96714886581	13.78459268487
10.	20.0	20.0	13.69498693797	8.00334923894	12.92806766945
15.	22.5	22.5	13.40318848534	8.01231353628	12.64977793016
20.	25.0	25.0	11.95164184892	6.90656458568	11.28234990538
25.	27.5	27.5	13.11320861588	6.57639921781	12.37886893339
30.	30.0	30.0	11.54139843745	6.62292862925	10.89508012496
35.	32.5	32.5	13.07486345339	7.24439849638	12.34267110000
40.	35.0	35.0	11.93985018012	6.07340572773	11.27121857003
45.	37.5	37.5	13.22456724919	7.50163039972	12.48399148323
50.	40.0	40.0	11.10498006529	7.10483353160	10.48225158164
55.	42.5	42.5	13.77059434028	7.79385948989	12.99944105722
60.	45.0	45.0	12.94762879512	7.10105500598	12.22256158259

Table A11. Static simulation results; $\sigma_B = 30$, $z_f = 500$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 30. CUTOFF ALT= 500. TERM VEL= 200.

RS (KM)	AT (KM)	RT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	65.00048355262	32.97068451759	61.36045647367
2.	16.0	16.0	46.95923011036	23.42599456961	44.32951322418
3.	16.5	16.5	39.91796163703	20.27721111595	37.68255578535
4.	17.0	17.0	37.02652820267	22.41301612825	34.95304262332
5.	17.5	17.5	39.17841087015	20.55897823683	36.98441986142
10.	20.0	20.0	38.92111553505	22.46012557458	36.74153306509
15.	22.5	22.5	38.19639425374	20.47080409043	36.05739617553
20.	25.0	25.0	33.43243185517	18.76593709506	31.56021567128
25.	27.5	27.5	38.17567068370	21.08697507526	36.03783312541
30.	30.0	30.0	38.18044360145	24.77670412812	36.04233875977
35.	32.5	32.5	36.96264450335	21.59888384703	34.89273641116
40.	35.0	35.0	37.89717575820	22.57646344994	35.77493391575
45.	37.5	37.5	34.04269053939	20.31092901704	32.13629986918
50.	40.0	40.0	36.02889625142	18.77478547917	34.01127806134
55.	42.5	42.5	39.10504026261	20.19314283505	36.91515800790
60.	45.0	45.0	38.23488860792	18.19284531429	36.09373484587

Table A12. Static simulation results; $\sigma_B = 50$, $z_f = 0$, $V_T = 200$

RX= 15000. RY= 15000. SIGR= 50. CUTOFF ALT= 500. TERM VEL= 200.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	109.70557122055	53.84971443558	103.56205923220
2.	16.0	16.0	78.99665722935	39.33584657044	74.57284442450
3.	16.5	16.5	65.40175726752	35.07059028585	61.73925886054
4.	17.0	17.0	64.84503091352	37.41133480401	61.21370918236
5.	17.5	17.5	67.25434694028	37.67952037584	63.48810351163
10.	20.0	20.0	62.60542287279	34.07057309666	59.09951919191
15.	22.5	22.5	59.90709990722	31.47091494521	56.55230231241
20.	25.0	25.0	59.24685386240	33.16438835528	55.92903004611
25.	27.5	27.5	64.67771577471	36.99686980375	61.05576369132
30.	30.0	30.0	57.81729669141	30.53062939910	54.57952807669
35.	32.5	32.5	57.35237387740	33.22779756329	54.14064094027
40.	35.0	35.0	64.68787450076	38.48348631378	61.06535352872
45.	37.5	37.5	63.14855750502	36.93616978777	59.61223828474
50.	40.0	40.0	57.31247911246	29.60222599681	54.10298028216
55.	42.5	42.5	64.86861248238	38.50285462806	61.23597018336
60.	45.0	45.0	63.42318859398	38.98764122198	59.87149003271

Table A13. Static simulation results; $\sigma_B = 1$, $z_f = 1000$, $V_T = 200$

RX= 15000. RY= 15000. SIGR= 1. CUTOFF ALT= 1000. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	3.69502823620	2.01704561756	3.48810665497
2.	16.0	16.0	2.23410627377	1.35336862314	2.10899632244
3.	16.5	16.5	1.71700218651	.89400233841	1.62085006406
4.	17.0	17.0	1.52294108862	.78954812970	1.43765638766
5.	17.5	17.5	1.49334331014	.85547836073	1.40971608477
10.	20.0	20.0	1.19647247910	.76631524139	1.12947002027
15.	22.5	22.5	1.27116114625	.64852913418	1.1999761222[illegible]6
20.	25.0	25.0	1.27827831447	.79242117758	1.20669472886
25.	27.5	27.5	1.31669776343	.75885359532	1.24296268868
30.	30.0	30.0	1.17840055651	.64484474233	1.11241012535
35.	32.5	32.5	1.17415989509	.67255151591	1.10840694096
40.	35.0	35.0	1.29437181529	.74161956506	1.22188699364
45.	37.5	37.5	1.30609599936	.81408251417	1.23295462339
50.	40.0	40.0	1.23913080962	.63446915379	1.16973948428
55.	42.5	42.5	1.20444229905	.71343026545	1.13699353031
60.	45.0	45.0	1.20637886936	.73084901762	1.13882165268

Table A14. Static simulation results; $\sigma_B = 4$, $z_f = 1000$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 4. CUTOFF ALT= 1000. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	14.98173977463	8.02225125553	14.14276234725
2.	16.0	16.0	7.88057640461	4.22098065015	7.43926412595
3.	16.5	16.5	6.28339212725	3.47063030770	5.93152216812
4.	17.0	17.0	5.83917809481	3.14735468188	5.51218412150
5.	17.5	17.5	5.32622876038	2.64768890544	5.02795994980
10.	20.0	20.0	4.73161465080	2.52929061802	4.46664423035
15.	22.5	22.5	5.19041477975	2.94007854911	4.89975155209
20.	25.0	25.0	4.92412862472	2.59342170729	4.64837742173
25.	27.5	27.5	4.77703878299	2.90010115553	4.50952461114
30.	30.0	30.0	4.94600744074	2.79415402463	4.66903102406
35.	32.5	32.5	4.95294248277	2.85117189174	4.67557770374
40.	35.0	35.0	5.33142784346	3.33481530628	5.03286788422
45.	37.5	37.5	5.06389263282	2.75065023537	4.78031464538
50.	40.0	40.0	5.33553015121	2.83428106178	5.03674046274
55.	42.5	42.5	4.54291514386	2.50018277111	4.28851189581
60.	45.0	45.0	4.44502526622	2.52755737120	4.19610385131

Table A15. Static simulation results; $\sigma_B = 7$, $z_f = 1000$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 7. CUTOFF ALT= 1000. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	23.90012865775	14.05873561854	22.56172145292
2.	16.0	16.0	15.79654344658	7.76739913650	14.91193701357
3.	16.5	16.5	12.65395392129	6.77592422720	11.94533250170
4.	17.0	17.0	9.96280631903	5.21608456820	9.40488916516
5.	17.5	17.5	10.41838033765	4.96507884333	9.83495103875
10.	20.0	20.0	8.06165316517	4.01670174329	7.61020058792
15.	22.5	22.5	9.02139580656	5.35686471051	8.51619764139
20.	25.0	25.0	9.07886005371	4.94244864339	8.57044389070
25.	27.5	27.5	9.00775068126	4.96837733467	8.50331664310
30.	30.0	30.0	8.21232852907	4.44925281133	7.75243813144
35.	32.5	32.5	8.57531843191	4.78638498328	8.09510059973
40.	35.0	35.0	7.88190678794	3.95712018619	7.44052000782
45.	37.5	37.5	8.92991313818	5.49978011112	8.42983800244
50.	40.0	40.0	8.66804449114	4.54527620157	8.18263399964
55.	42.5	42.5	8.89360489694	5.56592395409	8.39556302272
60.	45.0	45.0	8.61949974015	4.62619256253	8.13680775470

Table A16. Static simulation results; $\sigma_B = 10$, $z_f = 1000$, $V_T = 200$

RX= 15000. RY= 15000. SIGR= 10. CUTOFF ALT= 1000. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	40.41002771498	22.45927602723	38.14706616294
2.	16.0	16.0	20.40705354530	11.73883965880	19.26425854677
3.	16.5	16.5	16.21502015936	8.89413763716	15.30697903043
4.	17.0	17.0	15.13069869349	8.08224075571	14.28337956665
5.	17.5	17.5	14.66216135251	7.55140812041	13.84108031677
10.	20.0	20.0	12.51110385409	6.84804491728	11.81048203826
15.	22.5	22.5	12.25851034961	6.35115964086	11.57203377003
20.	25.0	25.0	13.17748581537	7.02427298944	12.43954660971
25.	27.5	27.5	12.61435598153	5.95704182702	11.90795204656
30.	30.0	30.0	13.26633528018	6.76933855763	12.52342050449
35.	32.5	32.5	12.20287540352	7.23193917067	11.51951438092
40.	35.0	35.0	11.21663197026	5.83129669592	10.58850057992
45.	37.5	37.5	12.72396025452	6.76147564473	12.01141848027
50.	40.0	40.0	11.87633592460	6.45730139173	11.21126111282
55.	42.5	42.5	11.98616711477	7.32061891841	11.31494175634
60.	45.0	45.0	11.39134357928	6.71986893321	10.75342833884

Table A17. Static simulation results; $\sigma_B = 30$, $z_f = 1000$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 30. CUTOFF ALT= 1000. TERM VEL= 200.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	114.42426318409	54.39546648965	108.01650444578
2.	16.0	16.0	62.12200937145	28.78731891929	58.64317684665
3.	16.5	16.5	54.07799584482	28.97749656852	51.04962807751
4.	17.0	17.0	45.59064242533	22.09032453438	43.03756644951
5.	17.5	17.5	47.02276285629	24.98712644494	44.38948813634
10.	20.0	20.0	37.56654499264	22.01670298027	35.46281847305
15.	22.5	22.5	33.63953305609	18.95219909248	31.75571920495
20.	25.0	25.0	36.47912385081	17.96313684330	34.43629291517
25.	27.5	27.5	40.03330415014	24.95948344464	37.79143911774
30.	30.0	30.0	36.82928621862	20.47532635966	34.76684619038
35.	32.5	32.5	37.47282764190	20.88116343665	35.37434929395
40.	35.0	35.0	37.11271211264	22.58985658590	35.03440023433
45.	37.5	37.5	34.80736557176	18.15626437497	32.85815309974
50.	40.0	40.0	37.25410816913	23.91668318491	35.16787811166
55.	42.5	42.5	36.35248848552	23.12734531437	34.31674913033
60.	45.0	45.0	40.84317139423	22.20351095284	38.55595379615

Table A18. Static simulation results; $\sigma_B = 50$, $z_f = 1000$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 50. CUTOFF ALT= 1000. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	179.06932150903	108.96549893550	169.04143950452
2.	16.0	16.0	115.38074321180	59.79674124128	108.91942159194
3.	16.5	16.5	85.60236772530	42.92937234532	80.80863513269
4.	17.0	17.0	75.05129637915	33.12145615405	70.84842378192
5.	17.5	17.5	77.48327313324	39.02507212491	73.14420983778
10.	20.0	20.0	62.63207905792	34.33868041432	59.12468263068
15.	22.5	22.5	65.63934580403	35.48137867490	61.96354243951
20.	25.0	25.0	63.45042953416	34.03957218143	59.89720548025
25.	27.5	27.5	65.57055798051	35.72900608867	61.89860673360
30.	30.0	30.0	64.78872349622	37.21903527698	61.16055498043
35.	32.5	32.5	58.25784552428	36.58289549898	54.99540617492
40.	35.0	35.0	64.59366291575	38.59540307722	60.97641779247
45.	37.5	37.5	62.27104409424	34.62296174125	58.78386562496
50.	40.0	40.0	59.85242732922	31.97754627836	56.50069139878
55.	42.5	42.5	60.77533754255	33.87049929496	57.37191864016
60.	45.0	45.0	66.20236312286	41.20470900380	62.49503078798

Table A19. Static simulation results; $\sigma_B = 1$, $z_f = 2000$, $V_T = 200$

RX= 15000. RY= 15000. STGR= 1. CUTOFF ALT= 2000. TERM VEL= 200.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	6.73846420331	3.60460005914	6.36111020792
2.	16.0	16.0	3.26362154994	1.64932334779	3.08085874314
3.	16.5	16.5	2.73516927472	1.37159348900	2.58199979534
4.	17.0	17.0	2.30726612617	1.15977672430	2.17805922311
5.	17.5	17.5	1.71021760717	.93766597640	1.61444542116
10.	20.0	20.0	1.41438176317	.74243625737	1.33517638443
15.	22.5	22.5	1.30108430186	.76203314087	1.22822358096
20.	25.0	25.0	1.23766846290	.70592924786	1.16835902897
25.	27.5	27.5	1.25822721173	.60994767163	1.18776648787
30.	30.0	30.0	1.14246260253	.66964548648	1.07848469679
35.	32.5	32.5	1.28267352781	.77135829085	1.21084381025
40.	35.0	35.0	1.30983665004	.69039337787	1.23648579764
45.	37.5	37.5	1.29580656609	.70289989176	1.22324139839
50.	40.0	40.0	1.32516519079	.80344383061	1.25095594011
55.	42.5	42.5	1.25384490089	.63745825348	1.18362958644
60.	45.0	45.0	1.35065706692	.77632631629	1.27502027117

Table A20. Static simulation results; $\sigma_B = 4$, $z_f = 2000$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 4. CUTOFF ALT= 2000. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	28.76238921533	15.93729121582	27.15169541927
2.	16.0	16.0	14.43496793223	6.80357300195	13.62660972803
3.	16.5	16.5	12.45338018294	5.35093827481	11.75599089269
4.	17.0	17.0	8.70522451829	4.55501287728	8.21773194526
5.	17.5	17.5	7.30204033419	4.42501188270	6.89312607548
10.	20.0	20.0	5.40207132921	2.72457242240	5.09955533477
15.	22.5	22.5	5.29530653180	3.07250745775	4.99876936601
20.	25.0	25.0	4.59361425135	2.54303986725	4.33637185327
25.	27.5	27.5	5.09008789196	2.58559777122	4.80504297001
30.	30.0	30.0	5.22275801340	2.64738175241	4.93028356465
35.	32.5	32.5	5.35644743873	3.05601996508	5.05648638216
40.	35.0	35.0	4.66999053690	2.62729029220	4.40847106683
45.	37.5	37.5	5.24551384992	3.33104965844	4.95176507432
50.	40.0	40.0	4.71952602756	2.60509423742	4.45523257002
55.	42.5	42.5	4.96116193724	2.84910471357	4.68333686876
60.	45.0	45.0	5.18074284062	2.99862359982	4.89062124155

Table A21. Static simulation results; $\sigma_B = 7$, $z_f = 2000$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 7. CUTOFF ALT= 2000. TERM VEL= 200.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	51.55852508921	34.20626537896	48.67124768421
2.	16.0	16.0	27.64238298679	14.77864226920	26.09440953953
3.	16.5	16.5	18.47984763360	9.16937982686	17.44497616612
4.	17.0	17.0	15.67562853785	7.82875785125	14.79779333973
5.	17.5	17.5	12.38206899536	6.89209441045	11.68867313162
10.	20.0	20.0	10.21417520345	5.33479601835	9.64218139266
15.	22.5	22.5	8.77008737454	4.77516450059	8.27896248157
20.	25.0	25.0	9.41423701552	5.26846694873	8.88703974265
25.	27.5	27.5	9.48212651865	5.17656193225	8.95112743360
30.	30.0	30.0	9.11221633378	4.97488789112	8.60193221969
35.	32.5	32.5	8.90049750135	4.75347257424	8.40206964128
40.	35.0	35.0	8.72065619221	4.89930783906	8.23229944544
45.	37.5	37.5	8.75096039212	5.26806256737	8.26090661016
50.	40.0	40.0	7.99284368996	4.37731631548	7.54524444333
55.	42.5	42.5	9.59943163327	5.57207680866	9.06186346180
60.	45.0	45.0	8.71125480143	4.50244985777	8.22342453255

Table A22. Static simulation results; $\sigma_B = 10$, $z_f = 2000$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 10. CUTOFF ALT= 2000. TERM VEL= 200.

RS (KM)	AT (KM)	RT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	68.99640106278	36.34302213251	65.13260260326
2.	16.0	16.0	39.43229602971	18.07100430624	37.22408745205
3.	16.5	16.5	25.04652684593	14.74020872430	23.64392134256
4.	17.0	17.0	22.99916706448	12.16505598285	21.71121370886
5.	17.5	17.5	19.74113150012	10.35239617888	18.63562813612
10.	20.0	20.0	15.70480278283	8.10497149497	14.82533382699
15.	22.5	22.5	12.23832712406	6.69146986436	11.55298080511
20.	25.0	25.0	12.30411288241	7.65764479912	11.61508256100
25.	27.5	27.5	12.55193664512	6.72809227233	11.84902819299
30.	30.0	30.0	11.43876907067	6.71808763353	10.79819800271
35.	32.5	32.5	13.73328807532	7.27649579945	12.96422394310
40.	35.0	35.0	13.44366564911	7.02523968217	12.69082037276
45.	37.5	37.5	12.63122483641	6.40730599601	11.92387624557
50.	40.0	40.0	12.25326441806	6.26094239344	11.56708161065
55.	42.5	42.5	12.66841659685	7.02925685975	11.95898526743
60.	45.0	45.0	11.92691016427	7.60525959554	11.25900319507

Table A23. Static simulation results; $\sigma_B = 30$, $z_f = 2000$, $V_T = 200$

RX= 15000. RY= 15000. SIGB= 30. CUTOFF ALT= 2000. TERM VEL= 200.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	200.29111691625	110.22216739070	189.07481436894
2.	16.0	16.0	105.27639799840	56.28512751212	99.38091971049
3.	16.5	16.5	80.27890267600	42.14000922507	75.78328412614
4.	17.0	17.0	64.52730416266	34.23454673099	60.91377512955
5.	17.5	17.5	51.81415064629	24.77775176157	48.91255821010
10.	20.0	20.0	43.67661368296	23.07381092712	41.23072331672
15.	22.5	22.5	40.19026744992	21.95245021402	37.93961247273
20.	25.0	25.0	42.22770186341	25.21329336744	39.86295055906
25.	27.5	27.5	40.98303655614	25.16586937528	38.68798650900
30.	30.0	30.0	40.48952203333	21.69046204781	38.22210879946
35.	32.5	32.5	38.48890312696	22.09316727080	36.33352455185
40.	35.0	35.0	37.61005760017	19.66087038514	35.50389437456
45.	37.5	37.5	38.94229619647	21.68633117729	36.76152760947
50.	40.0	40.0	39.22099332292	21.47132295679	37.02461769683
55.	42.5	42.5	35.48740112985	20.40173162682	33.50010666658
60.	45.0	45.0	34.86326934224	18.20009362491	32.91092625908

Table A24. Static simulation results; $\sigma_B = 50,\ z_f = 2000,\ V_T = 200$

RX= 15000. RY= 15000. SIGB= 50. CUTOFF ALT= 2000. TERM VEL= 200.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	357.30897099422	179.16121108683	337.29966861854
2.	16.0	16.0	188.96109179318	108.17971609625	178.37927065276
3.	16.5	16.5	137.57878030493	70.08707805880	129.87436860785
4.	17.0	17.0	109.53376299264	65.61976543942	103.39987226505
5.	17.5	17.5	94.70713042676	49.09660131521	89.40353112287
10.	20.0	20.0	72.24467807489	41.22472812954	68.19897610269
15.	22.5	22.5	71.39286933884	37.33461775546	67.39486865586
20.	25.0	25.0	62.92933957510	33.99931090703	59.40529655889
25.	27.5	27.5	62.83605565484	32.46473472067	59.31723653817
30.	30.0	30.0	62.18418525206	32.90827472954	58.70187087794
35.	32.5	32.5	61.06650787644	35.03338291721	57.64678343536
40.	35.0	35.0	58.97113557582	37.31720193920	55.66875198358
45.	37.5	37.5	63.77693875807	34.74790472421	60.20543018762
50.	40.0	40.0	62.31139336946	36.21362121760	58.82195534077
55.	42.5	42.5	60.81466660645	32.70746626600	57.40904527649
60.	45.0	45.0	61.38213549439	32.31109992376	57.94473590671

Table A25. Static simulation results; $\sigma_B = 1$, $z_f = 500$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 1. CUTOFF ALT= 500. TERM VEL= 250.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	2.13809750625	1.16703563826	2.01836404590
2.	16.0	16.0	1.75689299197	.85418023854	1.65850698442
3.	16.5	16.5	1.29233848918	.84745[illegible]35132	1.21996753378
4.	17.0	17.0	1.27002288968	.72076339761	1.19890160785
5.	17.5	17.5	1.19019428403	.64272699628	1.12354340413
10.	20.0	20.0	1.33453617435	.68919299758	1.25980214859
15.	22.5	22.5	1.20612450489	.64653409939	1.13858153262
20.	25.0	25.0	1.34634330967	.75298097054	1.27094808433
25.	27.5	27.5	1.19863205411	.67467069084	1.13150865908
30.	30.0	30.0	1.23490829058	.68205653115	1.16575342631
35.	32.5	32.5	1.16411698010	.69605141715	1.09892642921
40.	35.0	35.0	1.08767682201	.61869701980	1.02676691998
45.	37.5	37.5	1.29434288314	.76274981924	1.22185968169
50.	40.0	40.0	1.23140909797	.71279797498	1.16245018848
55.	42.5	42.5	1.22321389686	.73123887468	1.15471391864
60.	45.0	45.0	1.19034723925	.71723038294	1.12368779385

Table A26. Static simulation results; $\sigma_B = 4$, $z_f = 500$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 4. CUTOFF ALT= 500. TERM VEL= 250.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	8.71142733480	4.76076403986	8.22358740406
2.	16.0	16.0	6.57912966959	3.38173809329	6.21069840809
3.	16.5	16.5	5.17245345847	2.52620036492	4.88279606480
4.	17.0	17.0	5.42388603325	2.57694797612	5.12014841538
5.	17.5	17.5	5.17089015398	2.57020943976	4.88132030536
10.	20.0	20.0	5.12275637021	2.88998839263	4.83588201348
15.	22.5	22.5	4.88355420117	2.87986081352	4.61007516590
20.	25.0	25.0	4.75897051647	2.23570631113	4.49246816755
25.	27.5	27.5	4.91192515836	3.08900672639	4.63685734949
30.	30.0	30.0	4.54679202615	2.84934294493	4.29217167269
35.	32.5	32.5	4.59139180515	2.63216520674	4.33427386466
40.	35.0	35.0	4.33157833523	2.51567414741	4.08900994846
45.	37.5	37.5	4.95415401339	2.49146423716	4.67672138864
50.	40.0	40.0	5.01987521233	2.61685955217	4.73876220044
55.	42.5	42.5	4.44696829773	2.54402652008	4.19793807306
60.	45.0	45.0	4.74548162430	2.85220530466	4.47973465334

Table A27. Static simulation results; $\sigma_B = 7$, $z_f = 500$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 7. CUTOFF ALT= 500. TERM VEL= 250.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	16.33122432193	8.33941463617	15.41667575990
2.	16.0	16.0	10.08672693297	5.78721179256	9.52187022472
3.	16.5	16.5	9.96844488942	5.48229194075	9.41021197561
4.	17.0	17.0	9.47776258655	5.02947254009	8.94700788171
5.	17.5	17.5	8.73468787794	4.70108809174	8.24554535677
10.	20.0	20.0	8.87609931294	4.37134153225	8.37903775141
15.	22.5	22.5	9.53740425105	4.81704717302	9.00330961299
20.	25.0	25.0	8.86104409842	5.39314528519	8.36482562891
25.	27.5	27.5	7.18642100268	4.01022046164	6.78398142653
30.	30.0	30.0	8.31537474399	5.26795595291	7.84971375833
35.	32.5	32.5	8.87469500477	5.44474399954	8.37771208450
40.	35.0	35.0	7.76310100739	4.53898469446	7.32836735098
45.	37.5	37.5	8.37760369211	4.51977100890	7.90845788535
50.	40.0	40.0	7.92709385765	4.38097319930	7.48317660162
55.	42.5	42.5	8.19922767707	5.33568248440	7.74007092716
60.	45.0	45.0	8.04074300035	4.93222574331	7.59046139233

Table A28. Static simulation results; $\sigma_B = 10$, $z_f = 500$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 10. CUTOFF ALT= 500. TERM VEL= 250.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	21.68522941446	10.85898613902	20.47085656725
2.	16.0	16.0	15.40877061255	8.06535882103	14.54587945824
3.	16.5	16.5	12.84862598054	7.06842808407	12.12910292563
4.	17.0	17.0	14.76783231139	7.72673053878	13.94083370195
5.	17.5	17.5	13.03867415694	7.44770315914	12.30850840415
10.	20.0	20.0	13.41732131698	7.54505784198	12.66595132323
15.	22.5	22.5	12.79365591876	7.57367150523	12.07721118731
20.	25.0	25.0	11.90887462971	5.89564312645	11.24197765044
25.	27.5	27.5	12.56024910090	7.56467745455	11.85687515125
30.	30.0	30.0	11.92168731882	6.90940045552	11.25407282897
35.	32.5	32.5	11.79581871651	6.19128777431	11.13525286839
40.	35.0	35.0	11.86666366611	6.79415242136	11.20213050081
45.	37.5	37.5	12.18528087081	6.09023602836	11.50290514205
50.	40.0	40.0	11.12752071095	5.41790839755	10.50437955113
55.	42.5	42.5	13.10290890702	7.59502169900	12.36914600823
60.	45.0	45.0	11.26949850685	6.65659822541	10.63840659046

Table A29. Static simulation results; $\sigma_B = 30$, $z_f = 500$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 30. CUTOFF ALT= 500. TERM VEL= 250.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	63.33418668222	34.66705511478	59.78747222861
2.	16.0	16.0	49.88882821534	29.89222281101	47.09505383528
3.	16.5	16.5	39.59574842038	20.42728593234	37.37838650884
4.	17.0	17.0	38.05643221076	24.51885076779	35.92527200696
5.	17.5	17.5	39.19577545159	23.63971338660	37.00081202630
10.	20.0	20.0	34.01061987773	20.25922212207	32.10602516457
15.	22.5	22.5	34.55872443693	20.75590943593	32.62343586846
20.	25.0	25.0	41.93182082863	23.45008083235	39.58363886223
25.	27.5	27.5	39.84674187212	22.62769716977	37.61532432728
30.	30.0	30.0	36.88707179679	19.73768433917	34.82139577617
35.	32.5	32.5	36.50311664348	20.69187055164	34.45894211145
40.	35.0	35.0	37.47514091559	18.13874341333	35.37653302431
45.	37.5	37.5	36.43222290245	20.52682058822	34.39201841991
50.	40.0	40.0	37.54063164251	21.47315032194	35.43835627053
55.	42.5	42.5	38.34355111436	22.13865371294	36.19631225196
60.	45.0	45.0	32.84741310082	18.85419240232	31.00795796717

Table A30. Static simulation results; $\sigma_B = 50$, $z_f = 500$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 50. CUTOFF ALT= 500. TERM VEL= 250.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	109.86365857181	56.03676553014	103.71129369179
2.	16.0	16.0	79.29416696702	41.89492723438	74.85369361687
3.	16.5	16.5	75.65989591117	42.55265374020	71.42294174014
4.	17.0	17.0	67.88127638694	35.24596548802	64.07992490927
5.	17.5	17.5	70.81000623059	39.05492495431	66.84464588168
10.	20.0	20.0	59.91371028564	32.05141547336	56.55854250964
15.	22.5	22.5	60.73087636183	33.87832166966	57.32994728557
20.	25.0	25.0	68.58721265774	36.61103305627	64.74632874891
25.	27.5	27.5	63.79904284997	35.43785728031	60.22629645037
30.	30.0	30.0	56.78984194658	35.83879790313	53.60961079757
35.	32.5	32.5	63.72976686155	39.87601632694	60.16089991731
40.	35.0	35.0	66.00820583776	35.51926232907	62.31174631085
45.	37.5	37.5	60.27117124975	33.15699614094	56.89598565976
50.	40.0	40.0	61.07801576716	36.68350860698	57.65764688420
55.	42.5	42.5	59.70345217972	31.74493527693	56.36005885766
60.	45.0	45.0	59.74547043415	35.72632678439	56.39972408984

Table A31. Static simulation results; $\sigma_B = 1$, $z_f = 1000$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 1. CUTOFF ALT= 1000. TERM VEL= 250.

RS (KM)	AT (KM)	RT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	3.84706224525	2.09788593245	3.63162675951
2.	16.0	16.0	2.16912271719	1.08965598099	2.04765184562
3.	16.5	16.5	1.85297655223	.94918879270	1.74920986530
4.	17.0	17.0	1.48301361493	.83636950047	1.39996485249
5.	17.5	17.5	1.45965562424	.73996918263	1.37791490929
10.	20.0	20.0	1.16995946900	.61871972933	1.10444173873
15.	22.5	22.5	1.25871670564	.75331166245	1.18822857012
20.	25.0	25.0	1.15452298152	.59674348190	1.08986969456
25.	27.5	27.5	1.22739254396	.67282801993	1.15865856150
30.	30.0	30.0	1.25035064451	.59590824814	1.18033100842
35.	32.5	32.5	1.23257716675	.63307272322	1.16355284541
40.	35.0	35.0	1.32934172936	.77730076728	1.25489859252
45.	37.5	37.5	1.11617261934	.67204705676	1.05366695265
50.	40.0	40.0	1.25699091631	.61069589072	1.18659942499
55.	42.5	42.5	1.12925600885	.69113134804	1.06601767236
60.	45.0	45.0	1.31416951651	.79441620984	1.24057602359

Table A32. Static simulation results; $\sigma_B = 4$, $z_f = 1000$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 4. CUTOFF ALT= 1000. TERM VEL= 250.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	16.61085125570	7.58536504842	15.68064358538
2.	16.0	16.0	8.40464433271	4.37652550971	7.93398425008
3.	16.5	16.5	7.27653392725	3.96829647081	6.86904802733
4.	17.0	17.0	6.58523161590	3.39144166671	6.21645864541
5.	17.5	17.5	5.53651240424	2.59301319513	5.22646770960
10.	20.0	20.0	5.13473251840	2.84383985362	4.84718749737
15.	22.5	22.5	4.70798429663	2.74982857762	4.44433717601
20.	25.0	25.0	4.29579925202	2.48014004808	4.05901049391
25.	27.5	27.5	4.91029307369	2.60101647403	4.63531666156
30.	30.0	30.0	4.59943362469	2.46358382239	4.34186534170
35.	32.5	32.5	5.09426415691	3.19157194538	4.80898536413
40.	35.0	35.0	4.64108291412	2.48271651583	4.38118227093
45.	37.5	37.5	5.10268358546	3.23409072347	4.81693330468
50.	40.0	40.0	4.97947951927	2.97832267751	4.70062866619
55.	42.5	42.5	5.38732477222	2.61978837135	5.08563458497
60.	45.0	45.0	4.57473204752	2.66756711887	4.31854705286

Table A33. Static simulation results; $\sigma_B = 7$, $z_f = 1000$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 7. CUTOFF ALT= 1000. TERM VEL= 250.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	23.77877989314	13.18154510562	22.44716821913
2.	16.0	16.0	15.17276009145	9.06491526219	14.32308552633
3.	16.5	16.5	11.50836880938	6.53090629019	10.86390015605
4.	17.0	17.0	10.86625868755	5.90797632320	10.25774820105
5.	17.5	17.5	10.35986094191	5.20642882840	9.77970872916
10.	20.0	20.0	8.50522918872	5.34198115418	8.02893635415
15.	22.5	22.5	8.73686858734	4.86264376154	8.24760394645
20.	25.0	25.0	8.46396234572	4.78292144782	7.98998045436
25.	27.5	27.5	8.43472840306	4.66594554696	7.96238361249
30.	30.0	30.0	9.05236987701	5.56521549564	8.54543716390
35.	32.5	32.5	9.24759445065	4.76308097704	8.72972916141
40.	35.0	35.0	9.36175618095	5.08896533911	8.83749783482
45.	37.5	37.5	8.88881865113	4.89239836947	8.39104480667
50.	40.0	40.0	9.79756838415	5.39035309466	9.24890455464
55.	42.5	42.5	9.21002158552	5.20537268690	8.69426037673
60.	45.0	45.0	8.14474129019	4.68158688944	7.68863577794

Table A34. Static simulation results; $\sigma_B = 10$, $z_f = 1000$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 10. CUTOFF ALT= 1000. TERM VEL= 250.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	36.60365779522	17.58141647787	34.55385295869
2.	16.0	16.0	20.78848030936	11.65810358158	19.62432541204
3.	16.5	16.5	18.49702903844	9.55375223857	17.46119541229
4.	17.0	17.0	15.49829908203	8.85072747502	14.63039433344
5.	17.5	17.5	14.12676181758	7.29337886364	13.33566315579
10.	20.0	20.0	12.26117050357	6.25627911631	11.57454495537
15.	22.5	22.5	12.65120724854	7.28387686369	11.94273964263
20.	25.0	25.0	12.19602668905	6.41653624316	11.51304919446
25.	27.5	27.5	10.79013989965	5.74436117241	10.18589206527
30.	30.0	30.0	11.24891650810	6.84929262774	10.61897718365
35.	32.5	32.5	12.71837277461	7.05289968619	12.00614389923
40.	35.0	35.0	12.21220893870	6.39145755514	11.52832523813
45.	37.5	37.5	12.76583837673	6.47591399992	12.05095142764
50.	40.0	40.0	13.49042848769	7.47673125756	12.73496449238
55.	42.5	42.5	11.84628141376	5.88617721128	11.18288965459
60.	45.0	45.0	12.74096816931	6.17313459908	12.02747395183

Table A35. Static simulation results; $\sigma_B = 30$, $z_f = 1000$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 30. CUTOFF ALT= 1000. TERM VEL= 250.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	108.72445727814	56.63760200094	102.63588767056
2.	16.0	16.0	66.83911230004	31.21278958462	63.09612201124
3.	16.5	16.5	46.96922425053	27.05880172699	44.33894769250
4.	17.0	17.0	45.38695496223	24.34640435953	42.84528548434
5.	17.5	17.5	45.11640842360	24.96482199670	42.58988955188
10.	20.0	20.0	34.96024964799	18.20110650997	33.00247566770
15.	22.5	22.5	37.22991734081	21.56615752944	35.14504196972
20.	25.0	25.0	38.77513549556	21.00918842589	36.60372790781
25.	27.5	27.5	35.33720936250	20.08337293105	33.35832563820
30.	30.0	30.0	37.32220738431	23.27763024572	35.23216377079
35.	32.5	32.5	40.46922792177	21.45866080858	38.20295115815
40.	35.0	35.0	35.25831056754	18.71065284104	33.28384517576
45.	37.5	37.5	33.59894434614	21.87642614718	31.71740346276
50.	40.0	40.0	39.39215183841	19.70518721620	37.18619133546
55.	42.5	42.5	38.51372901798	21.38761520752	36.35696019297
60.	45.0	45.0	35.70100107243	20.49574234516	33.70174501238

Table A36. Static simulation results; $\sigma_B = 50$, $z_f = 1000$, $V_T = 250$

RX= 15000. RY= 15000. SIGR= 50. CUTOFF ALT= 1000. TERM VEL= 250.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	190.69875953841	117.05058526598	180.01962900425
2.	16.0	16.0	107.35282637784	55.93791301486	101.34106810068
3.	16.5	16.5	88.79036114845	42.79068501290	83.81810092414
4.	17.0	17.0	78.13745332897	42.30861703260	73.76175594255
5.	17.5	17.5	73.43131013179	37.00064112849	69.31915676441
10.	20.0	20.0	62.55268060328	36.68755729668	59.04973048950
15.	22.5	22.5	61.82490761872	33.36747123033	58.36271279258
20.	25.0	25.0	64.05988809751	38.07418101659	60.47253436405
25.	27.5	27.5	68.89165380298	35.93476043743	65.03372119001
30.	30.0	30.0	56.57175330433	31.31806942349	53.40373511929
35.	32.5	32.5	62.64313057529	36.41406571074	59.13511526308
40.	35.0	35.0	61.01549017038	33.94482073504	57.59862272083
45.	37.5	37.5	64.41237005267	38.21773797243	60.80527732972
50.	40.0	40.0	65.16009681186	35.09328961078	61.51113139040
55.	42.5	42.5	68.71620945473	42.45910435837	64.86810172526
60.	45.0	45.0	59.99689561470	32.72326645982	56.63706946027

Table A37. Static simulation results; $\sigma_B = 1$, $z_f = 2000$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 1. CUTOFF ALT= 2000. TERM VEL= 250.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	6.79379648527	3.80070084729	6.41334388209
2.	16.0	16.0	3.49491536173	1.87471077874	3.29920010147
3.	16.5	16.5	2.65862338279	1.28358838609	2.50974047335
4.	17.0	17.0	2.13661707186	1.13940648806	2.01696651583
5.	17.5	17.5	1.92223473712	1.11970043888	1.81458959185
10.	20.0	20.0	1.47845372324	.74670298932	1.39566031474
15.	22.5	22.5	1.30823616042	.65097171728	1.23497493543
20.	25.0	25.0	1.26892632345	.78054462619	1.19786644934
25.	27.5	27.5	1.34383372990	.75341010227	1.26857904102
30.	30.0	30.0	1.36773960545	.64755047740	1.29114618754
35.	32.5	32.5	1.30090044841	.65670210795	1.22805002330
40.	35.0	35.0	1.22993293804	.74937600335	1.16105669351
45.	37.5	37.5	1.24136661321	.64658678856	1.17185008287
50.	40.0	40.0	1.15366088003	.68127665087	1.08905587075
55.	42.5	42.5	1.13476481153	.65560937167	1.07121798208
60.	45.0	45.0	1.24577941293	.69358017633	1.17601576581

Table A38. Static simulation results; $\sigma_B = 4$, $z_f = 2000$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 4. CUTOFF ALT= 2000. TERM VEL= 250.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	26.70109242543	15.06497661735	25.20583124960
2.	16.0	16.0	15.45196719279	8.85227311812	14.58665703093
3.	16.5	16.5	10.52656083784	5.18445625277	9.93707343093
4.	17.0	17.0	8.52961622148	4.95190531777	8.05195771308
5.	17.5	17.5	7.41838024431	4.16309263874	7.00295095063
10.	20.0	20.0	5.95721201347	3.08133830645	5.62360814072
15.	22.5	22.5	5.14989350960	2.64156170073	4.86149947306
20.	25.0	25.0	5.33622132854	2.82299190188	5.03739293414
25.	27.5	27.5	4.95403032238	2.90774590350	4.67660462433
30.	30.0	30.0	5.47372513183	3.40024914157	5.16719652445
35.	32.5	32.5	4.71932653165	2.69112565778	4.45504424588
40.	35.0	35.0	4.79192819470	2.67221633816	4.52358021579
45.	37.5	37.5	4.76669098099	2.90801693812	4.49975628605
50.	40.0	40.0	4.73390299532	2.84512311159	4.46880442758
55.	42.5	42.5	4.77982021908	2.70112953271	4.51215028681
60.	45.0	45.0	5.44201698479	2.75372751448	5.13726403365

Table A39. Static simulation results; $\sigma_B = 7$, $z_f = 2000$, $V_T = 250$

RX= 15000. RY= 15000. SIGR= 7. CUTOFF ALT= 2000. TERM VEL= 250.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	49.21067504734	28.12437786190	46.45487724469
2.	16.0	16.0	26.00020271722	13.22827901455	24.54419136506
3.	16.5	16.5	18.66300940367	9.28257042786	17.61788087706
4.	17.0	17.0	15.95563109230	7.45181443120	15.06211575113
5.	17.5	17.5	12.15556242516	6.50172012986	11.47485092935
10.	20.0	20.0	10.39114513365	5.16125074783	9.80924100616
15.	22.5	22.5	9.08651675381	5.09179629815	8.57767181560
20.	25.0	25.0	8.89617676678	5.06860876997	8.39799086784
25.	27.5	27.5	8.54634520168	4.40793750357	8.06774987039
30.	30.0	30.0	9.61626709046	4.56878596622	9.07775613340
35.	32.5	32.5	8.93211464359	5.18952912895	8.43191622355
40.	35.0	35.0	8.53328043750	4.99708382679	8.05541673300
45.	37.5	37.5	8.71387141805	4.46448058315	8.22589461864
50.	40.0	40.0	8.82442297013	4.79492731895	8.33025528381
55.	42.5	42.5	8.95983759686	4.97673262524	8.45808669143
60.	45.0	45.0	9.68829075993	5.07069025864	9.14574647738

Table A40. Static simulation results; $\sigma_B = 10$, $z_f = 2000$, $V_T = 250$

RX= 15000. RY= 15000. SIGR= 10. CUTOFF ALT= 2000. TERM VEL= 250.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	66.58690444436	37.80648192538	62.85803779548
2.	16.0	16.0	38.95632882101	19.44355023331	36.77477440703
3.	16.5	16.5	25.35189979621	15.57205656258	23.93219340762
4.	17.0	17.0	22.10982743978	11.20682880294	20.87167710315
5.	17.5	17.5	19.08729827129	10.67611629545	18.01840956810
10.	20.0	20.0	13.59092901798	6.90576244293	12.82983699298
15.	22.5	22.5	12.48512671538	6.91861286144	11.78595961932
20.	25.0	25.0	12.20638292376	6.07112821756	11.52282548003
25.	27.5	27.5	12.69312567331	7.55480299617	11.98231063561
30.	30.0	30.0	11.73738488231	6.06521270503	11.08009132890
35.	32.5	32.5	12.29860677380	7.79174734222	11.60988479446
40.	35.0	35.0	12.30518342439	6.76177946271	11.61609315262
45.	37.5	37.5	11.65374313814	6.75419626392	11.00113352241
50.	40.0	40.0	12.86373575431	7.57110472382	12.14336655207
55.	42.5	42.5	12.38067908950	6.87108680108	11.68736106048
60.	45.0	45.0	12.87008442762	7.33678707361	12.14935969967

Table A41. Static simulation results; $\sigma_B = 30$, $z_f = 2000$, $V_T = 250$

RX= 15000. RY= 15000. SIGB= 30. CUTOFF ALT= 2000. TERM VEL= 250.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	209.90474127049	112.30759309636	198.15007575934
2.	16.0	16.0	111.37187652735	62.58175412247	105.13505144182
3.	16.5	16.5	76.36729047382	41.55411966838	72.09072220728
4.	17.0	17.0	63.70875983079	33.59929720278	60.14106928026
5.	17.5	17.5	60.97281312242	31.25921435289	57.55833558756
10.	20.0	20.0	38.02577311239	22.65067507491	35.89632981810
15.	22.5	22.5	38.75303542489	22.14834165413	36.58286544110
20.	25.0	25.0	37.00332309816	21.43048139187	34.93113700466
25.	27.5	27.5	39.92296775933	21.74587004538	37.68728156481
30.	30.0	30.0	35.51470562071	22.36601190549	33.52588210595
35.	32.5	32.5	40.13946315119	22.98411532456	37.89165321472
40.	35.0	35.0	36.68249517446	20.72161961353	34.62827544469
45.	37.5	37.5	35.59235036531	17.96245121867	33.59917874485
50.	40.0	40.0	35.88766775591	19.32102933288	33.87795836158
55.	42.5	42.5	39.69181672369	21.21012211171	37.46907498717
60.	45.0	45.0	35.11467529155	17.04134862191	33.14825347522

Table A42. Static simulation results; $\sigma_B = 50$, $z_f = 2000$, $V_T = 250$

PX= 15000. PY= 15000. STGR= 50. CUTOFF ALT= 2000. TERM VEL= 250.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	348.57142523612	181.51173236748	329.05142542289
2.	16.0	16.0	180.46415600372	95.69722250510	170.35816326752
3.	16.5	16.5	129.09885231076	71.52884473528	121.86931658135
4.	17.0	17.0	116.39377745761	59.68314636980	109.87572591998
5.	17.5	17.5	93.59326459754	45.59919053987	88.35204178008
10.	20.0	20.0	71.85494904232	39.27249841835	67.83107189595
15.	22.5	22.5	65.33980596630	30.38819761395	61.68077683218
20.	25.0	25.0	62.00328623796	34.46245643744	58.53110220863
25.	27.5	27.5	63.44256655445	34.44020681506	59.88978282740
30.	30.0	30.0	64.68954643836	40.09558504260	61.06693183781
35.	32.5	32.5	71.38774538157	41.19488149022	67.39003164020
40.	35.0	35.0	62.28692032991	36.68726981455	58.79885279144
45.	37.5	37.5	64.51510048889	34.27902951587	60.90225486151
50.	40.0	40.0	60.53721358946	29.61733242054	57.14712962845
55.	42.5	42.5	61.46262524789	36.54617083657	58.02071823401
60.	45.0	45.0	70.00515858632	40.08973758128	66.08486970549

Table A43. Static simulation results; $\sigma_B = 1$, $z_f = 500$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 1. CUTOFF ALT= 500. TERM VEL= 300.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	2.16039766473	1.09816459057	2.03941539550
2.	16.0	16.0	1.42800036495	.84441899520	1.34803234451
3.	16.5	16.5	1.37337077808	.72438707514	1.29646201451
4.	17.0	17.0	1.28404534067	.62353562687	1.21213880159
5.	17.5	17.5	1.15923218712	.70524365219	1.09431518464
10.	20.0	20.0	1.34758120869	.65370562037	1.27211666190
15.	22.5	22.5	1.27197309428	.73433397353	1.20074260100
20.	25.0	25.0	1.13780226111	.69517854629	1.07408533449
25.	27.5	27.5	1.14455591870	.65031293771	1.08046078726
30.	30.0	30.0	1.15458823194	.66497303518	1.08993129096
35.	32.5	32.5	1.27960171143	.59028193479	1.20794401559
40.	35.0	35.0	1.18931481350	.62309141364	1.12271318394
45.	37.5	37.5	1.36932187104	.77673322676	1.29263984626
50.	40.0	40.0	1.22075239464	.66542537523	1.15239026054
55.	42.5	42.5	1.25336769958	.65093884100	1.18317910841
60.	45.0	45.0	1.22711116847	.63466889375	1.15839294304

Table A44. Static simulation results; $\sigma_B = 4$, $z_f = 500$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 4. CUTOFF ALT= 500. TERM VEL= 300.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	8.51473330480	4.48332828308	8.03790823973
2.	16.0	16.0	6.20703560198	3.78686581013	5.85944160827
3.	16.5	16.5	5.50854986719	2.96335305129	5.20007107462
4.	17.0	17.0	5.23155445151	2.76028179035	4.93858740223
5.	17.5	17.5	4.92869593929	2.83280359368	4.65268896669
10.	20.0	20.0	4.82220989989	3.18847610780	4.55783014550
15.	22.5	22.5	4.98401456543	2.54863803143	4.70490974977
20.	25.0	25.0	5.30422084941	2.67275927585	5.00718448185
25.	27.5	27.5	5.48800036790	3.08535717704	5.18067234729
30.	30.0	30.0	5.42626885558	2.82091891332	5.12239779967
35.	32.5	32.5	4.57576499023	2.71515393763	4.31952215078
40.	35.0	35.0	5.10283717595	2.70197468077	4.81707829410
45.	37.5	37.5	4.97340588973	3.00722519142	4.69489515991
50.	40.0	40.0	5.15654157205	2.73581350468	4.86777524401
55.	42.5	42.5	4.80283661360	2.97743028070	4.53387776324
60.	45.0	45.0	4.73658834685	2.82330020257	4.47133939943

Table A45. Static simulation results; $\sigma_B = 7$, $z_f = 500$, $V_T = 300$

PX= 15000. PY= 15000. SIGR= 7. CUTOFF ALT= 500. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	14.83976219322	7.38785121358	14.00873551040
2.	16.0	16.0	11.93207153359	5.75929928682	11.26387552770
3.	16.5	16.5	9.79938006206	4.94251809035	9.25061477859
4.	17.0	17.0	9.63154033009	5.59079889993	9.09217407161
5.	17.5	17.5	9.67492560117	5.14886228206	9.13312976750
10.	20.0	20.0	9.14862829062	5.27551721604	8.63630510634
15.	22.5	22.5	8.65469556479	5.00167687640	8.17003261316
20.	25.0	25.0	9.51920493838	5.73068672126	8.98612946183
25.	27.5	27.5	8.28629837654	4.55037588112	7.82226566745
30.	30.0	30.0	8.53471670940	4.88448535853	8.05677257368
35.	32.5	32.5	8.38818477527	4.53453408713	7.91844642785
40.	35.0	35.0	7.77566907289	3.29894378334	7.34023160481
45.	37.5	37.5	9.53756248948	5.73754491188	9.00345899007
50.	40.0	40.0	8.50489891744	4.92499823897	8.02862457806
55.	42.5	42.5	9.17182330694	5.75694973360	8.65820120175
60.	45.0	45.0	8.16974430177	4.60908621497	7.71223862087

Table A46. Static simulation results; $\sigma_B = 10$, $z_f = 500$, $V_T = 300$

RX= 15000. RY= 15000. SIGR= 10. CUTOFF ALT= 500. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	21.69966153049	13.08523857660	20.48448048478
2.	16.0	16.0	17.47948589716	9.15352163784	16.50063468691
3.	16.5	16.5	14.00981046844	7.88189713759	13.22526108221
4.	17.0	17.0	13.34352482809	7.98743630649	12.59628743771
5.	17.5	17.5	13.33554665528	7.05305630370	12.58875604258
10.	20.0	20.0	11.82732182357	6.71438636207	11.16499180145
15.	22.5	22.5	11.77620643862	6.87765320561	11.11673887806
20.	25.0	25.0	11.81106296849	6.23130888379	11.14964344226
25.	27.5	27.5	13.45329773968	7.37357115988	12.69991306625
30.	30.0	30.0	12.01078965913	6.46579161659	11.33818543822
35.	32.5	32.5	12.52768793041	7.35480642974	11.82613740631
40.	35.0	35.0	11.87712475110	5.97882778596	11.21200576504
45.	37.5	37.5	11.09542762608	6.42744092572	10.47408367902
50.	40.0	40.0	12.10238619168	7.61072869949	11.42465256494
55.	42.5	42.5	11.42948264843	6.75775668943	10.78943163011
60.	45.0	45.0	13.21150541564	7.39401704735	12.47166111236

Table A47. Static simulation results; $\sigma_B = 30$, $z_f = 500$, $V_T = 300$

RX= 15000. PY= 15000. SIGB= 30. CUTOFF ALT= 500. TERM VEL= 300.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	66.73239920152	34.35943586138	62.99538484624
2.	16.0	16.0	46.70840697756	23.49378768987	44.09273618681
3.	16.5	16.5	43.52330453165	20.32434066239	41.08599947788
4.	17.0	17.0	41.84597814884	22.49772967969	39.50260337250
5.	17.5	17.5	37.95559185458	21.37470254703	35.83007871073
10.	20.0	20.0	36.42095979254	20.77540090322	34.38138604415
15.	22.5	22.5	36.24092410369	20.55127951741	34.21143235388
20.	25.0	25.0	39.95072077966	22.14960010914	37.71348041600
25.	27.5	27.5	35.77365263577	17.67850219474	33.77032808817
30.	30.0	30.0	40.37436846209	21.32055935905	38.11340382821
35.	32.5	32.5	35.37694442935	18.96875967480	33.39583554131
40.	35.0	35.0	37.90183441938	19.29958788216	35.77933169190
45.	37.5	37.5	33.53013025057	19.71759633551	31.65244295654
50.	40.0	40.0	40.11349815800	22.08403239721	37.86714226115
55.	42.5	42.5	35.90663116889	20.54002226614	33.89585982343
60.	45.0	45.0	35.62227828818	20.73825640766	33.62743070404

Table A48. Static simulation results; $\sigma_B = 50$, $z_f = 500$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 50. CUTOFF ALT= 500. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	108.49710083321	53.31120462251	102.42126318655
2.	16.0	16.0	72.85944101371	36.84632622770	68.77931231694
3.	16.5	16.5	71.13767401697	38.45257822469	67.15396427202
4.	17.0	17.0	65.04653132484	35.80720861654	61.40392557065
5.	17.5	17.5	58.29667385986	34.32125612222	55.03206012370
10.	20.0	20.0	67.70862462592	35.88183456050	63.91694164687
15.	22.5	22.5	61.36905934534	35.14542410109	57.93239202200
20.	25.0	25.0	60.27127308572	32.17797053146	56.89608179292
25.	27.5	27.5	65.59164008921	36.60159803499	61.91850824422
30.	30.0	30.0	60.66841701601	34.96305799962	57.27098566311
35.	32.5	32.5	61.96654888980	36.01542375737	58.49642215197
40.	35.0	35.0	55.59486322983	32.75361959689	52.48155088895
45.	37.5	37.5	57.02117106331	38.69164680063	53.82798548376
50.	40.0	40.0	65.78670226680	34.99096319411	62.10264693985
55.	42.5	42.5	62.94438899852	35.87586933353	59.41950321460
60.	45.0	45.0	63.52400525276	34.02735795009	59.96666095860

Table A49. Static simulation results; $\sigma_B = 1$, $z_f = 1000$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 1. CUTOFF ALT= 1000. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	4.09384309787	2.20552717358	3.86458788439
2.	16.0	16.0	1.98887479395	1.11919202787	1.87749780549
3.	16.5	16.5	1.85425971992	.86363609443	1.75042117561
4.	17.0	17.0	1.54062185952	.73457725459	1.45434703539
5.	17.5	17.5	1.37815577443	.74406007573	1.30097905106
10.	20.0	20.0	1.25692820929	.60347611974	1.18654022957
15.	22.5	22.5	1.19268982930	.60556231303	1.12589919886
20.	25.0	25.0	1.27389172618	.67034818182	1.20255378952
25.	27.5	27.5	1.24065979474	.67367906207	1.17118284623
30.	30.0	30.0	1.32524533447	.74907874786	1.25103159574
35.	32.5	32.5	1.27551209425	.70810286177	1.20408341697
40.	35.0	35.0	1.18490344791	.65185393810	1.11854885483
45.	37.5	37.5	1.12347930933	.65507248439	1.06056446801
50.	40.0	40.0	1.17719086496	.75834725596	1.11126817652
55.	42.5	42.5	1.19337339120	.69353750737	1.12654448129
60.	45.0	45.0	1.11782039900	.61607700104	1.05522245666

Table A50. Static simulation results; $\sigma_B = 4$, $z_f = 1000$, $V_T = 300$

RX= 15000. PY= 15000. STGR= 4. CUTOFF ALT= 1000. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	15.00728059629	7.97371811180	14.16687288290
2.	16.0	16.0	8.97300107755	4.79451025091	8.47051301721
3.	16.5	16.5	7.12522591212	3.54264422060	6.72621326104
4.	17.0	17.0	6.45645393484	2.93202664547	6.09489251449
5.	17.5	17.5	5.97237559136	3.28064977795	5.63792255825
10.	20.0	20.0	5.11797224854	2.91451421162	4.83136580262
15.	22.5	22.5	5.08938065256	2.77949100588	4.80437533602
20.	25.0	25.0	5.22077300310	2.67993646323	4.92840971493
25.	27.5	27.5	5.11638428894	2.47095703250	4.82986676876
30.	30.0	30.0	4.70619172218	2.96838050258	4.44264498574
35.	32.5	32.5	4.87346350673	2.69951289922	4.60054955036
40.	35.0	35.0	4.65345921450	2.85688634065	4.39286549848
45.	37.5	37.5	5.11148056876	2.87808804612	4.82523765691
50.	40.0	40.0	5.51335803187	2.76332916057	5.20460998208
55.	42.5	42.5	5.02618645085	2.75334142444	4.74472000961
60.	45.0	45.0	5.12692474964	2.81181041629	4.83981696366

Table A51. Static simulation results; $\sigma_B = 7$, $z_f = 1000$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 7. CUTOFF ALT= 1000. TERM VEL= 300.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	27.54841800444	14.64674813274	26.00570659619
2.	16.0	16.0	14.59799258890	7.20889848071	13.78050500392
3.	16.5	16.5	11.75539185627	6.06528260636	11.09708991232
4.	17.0	17.0	11.36849983050	5.85879675075	10.73186383999
5.	17.5	17.5	9.61943132892	4.27707542560	9.08074317450
10.	20.0	20.0	9.38419222074	4.38929207256	8.85867745638
15.	22.5	22.5	9.23700533997	5.31536669745	8.71973304093
20.	25.0	25.0	9.00938442313	5.12479540981	8.50485889543
25.	27.5	27.5	9.16928180843	4.95911052104	8.65580202716
30.	30.0	30.0	9.27906264090	5.58384528829	8.75943513301
35.	32.5	32.5	8.47363880574	4.41746530542	7.99911503262
40.	35.0	35.0	8.47241602496	4.03416816170	7.99796072756
45.	37.5	37.5	8.29396497650	4.51029988091	7.82950293781
50.	40.0	40.0	8.22627942475	5.55623981822	7.76560777697
55.	42.5	42.5	8.46169769149	5.21786792053	7.98784262077
60.	45.0	45.0	9.24535655727	5.70467356305	8.72761659007

Table A52. Static simulation results; $\sigma_B = 10$, $z_f = 1000$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 10. CUTOFF ALT= 1000. TERM VEL= 300.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	42.70034867649	20.09805387076	40.30912915060
2.	16.0	16.0	21.25166490453	11.11090950337	20.06157166988
3.	16.5	16.5	19.24190290447	8.99546162342	18.16435634182
4.	17.0	17.0	15.36904174434	8.39283774976	14.50837540666
5.	17.5	17.5	13.49288244580	7.09500370485	12.73728102883
10.	20.0	20.0	13.87120644695	6.97163864996	13.09441888592
15.	22.5	22.5	12.10665939575	6.64101825685	11.42868646959
20.	25.0	25.0	13.03741568079	6.91037884056	12.30732040266
25.	27.5	27.5	13.59853713444	7.47612259837	12.83701905491
30.	30.0	30.0	11.62581187298	6.91883456044	10.97476640810
35.	32.5	32.5	12.58383351893	5.95408431201	11.87913884187
40.	35.0	35.0	12.13684927133	7.36268883921	11.45718571213
45.	37.5	37.5	12.76286924965	6.85513156109	12.04814857167
50.	40.0	40.0	12.73141134577	7.75940278101	12.01845231041
55.	42.5	42.5	11.35390936385	6.61001537212	10.71809043948
60.	45.0	45.0	12.40732158567	7.23154856170	11.71251157687

Table A53. Static simulation results; $\sigma_B = 30$, $z_f = 1000$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 30. CUTOFF ALT= 1000. TERM VEL= 300.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	113.60578590910	63.33391843999	107.24386189819
2.	16.0	16.0	62.63210441391	31.19380371790	59.12470656673
3.	16.5	16.5	52.82172939042	25.79422208585	49.86371254455
4.	17.0	17.0	42.99493914753	24.72931441056	40.58722255526
5.	17.5	17.5	45.13445368360	23.87072829526	42.60692427732
10.	20.0	20.0	42.84579282237	19.90895991490	40.44642842431
15.	22.5	22.5	35.42095569116	21.96336267149	33.43738217245
20.	25.0	25.0	36.80251161877	20.17956789389	34.74157096812
25.	27.5	27.5	36.19257585916	20.46701628190	34.16579161104
30.	30.0	30.0	36.16341417602	21.26257365002	34.13826298216
35.	32.5	32.5	36.40196406499	20.85823629276	34.36345407735
40.	35.0	35.0	40.86247339424	21.91655618648	38.57417488416
45.	37.5	37.5	38.01945565988	18.00359127148	35.89036614293
50.	40.0	40.0	37.30852329753	22.98700569254	35.21924599287
55.	42.5	42.5	33.11881864325	18.33736552250	31.26416479923
60.	45.0	45.0	38.40974794749	21.88740100572	36.25880206243

Table A54. Static simulation results; $\sigma_B = 50$, $z_f = 1000$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 50. CUTOFF ALT= 1000. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	183.96748061807	98.84050692576	173.66530170346
2.	16.0	16.0	93.36427391285	55.50158402266	88.13587457373
3.	16.5	16.5	83.57900846556	46.52150492463	78.89858399149
4.	17.0	17.0	74.55080687577	36.68298520369	70.37596169073
5.	17.5	17.5	67.19221458927	39.12294577990	63.42945057227
10.	20.0	20.0	60.56544936377	31.42399143306	57.17378419940
15.	22.5	22.5	67.29302814632	37.32310795540	63.52461857013
20.	25.0	25.0	62.98919249550	38.31557569097	59.46179771576
25.	27.5	27.5	64.09513799223	35.97500583477	60.50581026466
30.	30.0	30.0	69.08220857524	36.21771942315	65.21360489503
35.	32.5	32.5	60.86272683384	30.60475541047	57.45441413115
40.	35.0	35.0	58.63990988911	31.77049565738	55.35607493532
45.	37.5	37.5	61.11647297476	38.08976127614	57.69395048817
50.	40.0	40.0	60.50915633828	35.11892909627	57.12064358334
55.	42.5	42.5	65.81579641400	39.43224988709	62.13011181481
60.	45.0	45.0	64.95668719237	36.99269283695	61.31911270960

Table A55. Static simulation results; $\sigma_B = 1$, $z_f = 2000$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 1. CUTOFF ALT= 2000. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	6.87965814220	3.76485364942	6.49439728623
2.	16.0	16.0	3.52625457275	2.00157479706	3.32878431667
3.	16.5	16.5	2.82279656410	1.55223310888	2.66471995651
4.	17.0	17.0	2.21524029937	1.08114910096	2.09118684260
5.	17.5	17.5	1.96621583513	.89409791864	1.85610774836
10.	20.0	20.0	1.37907409462	.65669017207	1.30184594532
15.	22.5	22.5	1.36535927977	.64078690397	1.28889916010
20.	25.0	25.0	1.36752133321	.75791694166	1.29094013855
25.	27.5	27.5	1.23382165722	.75013198265	1.16472764442
30.	30.0	30.0	1.30317606618	.63397239874	1.23019820647
35.	32.5	32.5	1.28025994336	.70484956145	1.20856538654
40.	35.0	35.0	1.16176492015	.68235634267	1.09670608462
45.	37.5	37.5	1.41703340312	.75232365191	1.33767953255
50.	40.0	40.0	1.28886278778	.68741714625	1.21668647166
55.	42.5	42.5	1.34090778804	.73946752942	1.26581695191
60.	45.0	45.0	1.24524212740	.69151372457	1.17550856827

Table A56. Static simulation results; $\sigma_B = 4$, $z_f = 2000$, $V_T = 300$

RX= 15000. RY= 15000. STGR= 4. CUTOFF ALT= 2000. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	30.68289367922	15.81975173530	28.96465163319
2.	16.0	16.0	14.56685507998	7.18764227807	13.75111119550
3.	16.5	16.5	10.37598785484	5.84702410880	9.79493253496
4.	17.0	17.0	8.81497967610	4.22517363391	8.32134081424
5.	17.5	17.5	7.28838057110	3.62059937873	6.88023125912
10.	20.0	20.0	5.87887989914	3.06670327968	5.54966262479
15.	22.5	22.5	5.32696035178	2.69003792394	5.02865057208
20.	25.0	25.0	5.06406832157	2.86396647559	4.78048049556
25.	27.5	27.5	5.18212591378	2.92327113374	4.89192686261
30.	30.0	30.0	5.01674764409	2.55029026047	4.73580977602
35.	32.5	32.5	5.42630720465	3.29827254268	5.12243400119
40.	35.0	35.0	4.86405282276	2.55269344736	4.59166586468
45.	37.5	37.5	5.46576366413	2.89820355821	5.15968089894
50.	40.0	40.0	4.73730049258	2.56627385953	4.47201166499
55.	42.5	42.5	5.22612998218	3.00787372738	4.93346670318
60.	45.0	45.0	5.63028614998	2.92386243832	5.31499012558

Table A57. Static simulation results; $\sigma_B = 7$, $z_f = 2000$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 7. CUTOFF ALT= 2000. TERM VEL= 300.

RS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	58.28445890105	34.97559263963	55.02052920259
2.	16.0	16.0	27.39395925699	14.81465344938	25.85989753860
3.	16.5	16.5	19.35958941418	10.60458161226	18.27545240698
4.	17.0	17.0	13.61143867585	7.29243237149	12.84919811000
5.	17.5	17.5	13.60914057960	6.42867904687	12.84702870714
10.	20.0	20.0	10.43914887553	5.67821651331	9.85455653850
15.	22.5	22.5	10.04703989746	5.09956088955	9.48440566320
20.	25.0	25.0	9.11110036658	4.63438602744	8.60087874606
25.	27.5	27.5	9.11552755574	4.19821656313	8.60505801262
30.	30.0	30.0	8.56283812162	4.74022148370	8.08331918681
35.	32.5	32.5	8.49175267655	4.47407741054	8.01621452666
40.	35.0	35.0	9.18567270968	5.45567482017	8.67127503794
45.	37.5	37.5	8.81252127521	4.61651241946	8.31902008380
50.	40.0	40.0	7.72819925430	4.40992745022	7.29542009606
55.	42.5	42.5	8.20874109913	4.39396478940	7.74905159758
60.	45.0	45.0	8.90460635240	4.92168170762	8.40594839667

Table A58. Static simulation results; $\sigma_B = 10$, $z_f = 2000$, $V_T = 300$

RX= 15000. RY= 15000. SIGB= 10. CUTOFF ALT= 2000. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	75.06730874703	40.41575968452	70.86353945720
2.	16.0	16.0	37.52373017425	20.42743747027	35.42240128449
3.	16.5	16.5	22.29378809814	13.93998322097	21.04533596464
4.	17.0	17.0	22.89887032502	11.38410483264	21.61653358682
5.	17.5	17.5	19.09056271245	10.06919400767	18.02149120055
10.	20.0	20.0	15.10289595052	7.60813185794	14.25713377729
15.	22.5	22.5	12.99498358841	6.92843970024	12.26726450745
20.	25.0	25.0	12.08660894245	6.62180339365	11.40975884167
25.	27.5	27.5	12.90978764512	8.46999700659	12.18683953699
30.	30.0	30.0	13.56876281792	6.82954778053	12.80891210012
35.	32.5	32.5	12.71816394078	6.99226389484	12.00594676010
40.	35.0	35.0	12.79680160421	7.10168232461	12.08018071437
45.	37.5	37.5	12.16034430585	6.80161399224	11.47936502472
50.	40.0	40.0	12.74529931961	6.33192644185	12.03156255676
55.	42.5	42.5	12.73620859291	7.10049100239	12.02298091171
60.	45.0	45.0	11.21020423233	6.73468937439	10.58243279532

Table A59. Static simulation results; $\sigma_B = 30$, $z_f = 2000$, $V_T = 300$

RX= 15000. PY= 15000. SIGR= 30. CUTOFF ALT= 2000. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	212.56240418518	111.88782819017	200.65890955081
2.	16.0	16.0	104.75973816237	60.45837230991	98.89319282527
3.	16.5	16.5	84.41006987428	43.60117544057	79.68310596132
4.	17.0	17.0	63.61279548989	29.23805860336	60.05047894245
5.	17.5	17.5	59.42113071722	28.82315362426	56.09354739705
10.	20.0	20.0	43.74389343178	23.58113558276	41.29423539960
15.	22.5	22.5	34.95382657234	20.58634906867	32.99641228429
20.	25.0	25.0	38.49553390794	23.06322293327	36.33978400909
25.	27.5	27.5	40.98545337200	23.43001982799	38.69026798316
30.	30.0	30.0	39.72401116691	23.26113479897	37.49946654156
35.	32.5	32.5	35.52793848046	17.72650728976	33.53837392556
40.	35.0	35.0	36.10218092976	22.35462881073	34.08045879769
45.	37.5	37.5	37.34149857714	20.11266949238	35.25037465682
50.	40.0	40.0	37.72621088348	19.20656231241	35.61354307401
55.	42.5	42.5	36.99300122028	19.64796346889	34.92139315194
60.	45.0	45.0	39.76757109614	19.31039061451	37.54058711476

Table A60. Static simulation results; $\sigma_B = 50$, $z_f = 2000$, $V_T = 300$

PX= 15000. PY= 15000. SIGR= 50. CUTOFF ALT= 2000. TERM VEL= 300.

BS (KM)	AT (KM)	BT (KM)	MEAN ERROR (M)	STANDARD DEVIATION (M)	RHO AT TARGET (CEP)
1.	15.5	15.5	365.78105402712	176.09294099135	345.29731500160
2.	16.0	16.0	174.71593302762	101.02497191827	164.93184077808
3.	16.5	16.5	127.46529607771	74.77854794550	120.32723949736
4.	17.0	17.0	116.04956075362	60.06368820446	109.55078535142
5.	17.5	17.5	93.50920082235	40.98637930702	88.27268557630
10.	20.0	20.0	68.42711773769	37.76358654074	64.59519914437
15.	22.5	22.5	60.66187549431	33.06786581449	57.26481046663
20.	25.0	25.0	57.50153480441	31.42494094098	54.28144885537
25.	27.5	27.5	68.01121298290	31.06674839492	64.20258505586
30.	30.0	30.0	65.23462171239	39.99747395573	61.58148289650
35.	32.5	32.5	64.91840750171	37.67180385569	61.28297668162
40.	35.0	35.0	64.03483895230	33.13326367232	60.44888797097
45.	37.5	37.5	69.57117512577	32.45979651910	65.67518931873
50.	40.0	40.0	65.65357887611	36.00889897016	61.97697845985
55.	42.5	42.5	63.80692396987	40.14478138223	60.23373622756
60.	45.0	45.0	67.50577568521	42.98323455346	63.72545224684

APPENDIX B

DYNAMIC SIMULATION RESULTS

Table B1. Dynamic simulation results, Case I, Geometry I

$(\rho \text{ cep})_c = 0.44$ meters

Run Number	X - Impact	Y - Impact
1	9899.19	9899.19
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19	9899.19	9899.19

Table B2. Dynamic simulation results, Case II, Geometry I

$(\rho \quad cep)_c = 7.5$ meters

Run Number	X- Impact	Y- Impact
1	9897.59	9902.09
2	9890.23	9894.29
3	9898.99	9899.09
4	9871.49	9887.93
5	9895.54	9902.22
6	9884.54	9895.71
7	9893.07	9902.38
8	9897.01	9901.94
9	9898.85	9889.61
10	9904.89	9898.09
11	9899.04	9896.97
12	9892.30	9903.00
13	9894.40	9903.20
14	9903.70	9897.03
15	9896.71	9900.49
16	9884.15	9896.71
17	9904.80	9903.43
18	9904.25	9895.42
19	9891.66	9905.31

Table B3. Dynamic simulation results, Case III, Geometry I

$(\rho \, cep)_c = 11.2$ meters

Run Number	X - Impact	Y - Impact
1	9912.64	9906.01
2	9889.31	9899.82
3	9893.92	9897.53
4	9904.52	9903.42
5	9905.54	9909.07
6	9889.06	9900.36
7	9896.88	9902.26
8	9920.22	9909.26
9	9884.17	9885.28
10	9897.48	9910.56
11	9884.28	9886.06
12	9904.56	9899.83
13	9907.95	9897.85
14	9900.02	9920.68
15	9901.84	9904.36
16	9896.69	9903.16
17	9893.87	9880.06
18	9896.54	9883.02
19	9896.34	9897.47

Table B4. Dynamic simulation results, Case IV, Geometry I

$(\rho\,\mathrm{cep})_c = 14.5$ meters

Run Number	X - Impact	Y - Impact
1	9911.19	9909.09
2	9880.56	9894.11
3	9893.90	9897.61
4	9890.77	9906.27
5	9902.04	9912.29
6	9888.44	9910.95
7	9890.95	9905.96
8	9918.22	9912.22
9	9883.93	9875.90
10	9903.35	9909.65
11	9884.27	9884.01
12	9897.85	9903.82
13	9903.33	9902.05
14	9904.64	9918.62
15	9899.53	9891.92
16	9881.80	9900.85
17	9899.68	9884.51
18	9901.75	9879.37
19	9888.99	9903.77

Table B5. Dynamic simulation results, Case I, Geometry II

$(\rho \; cep)_c = 0.44$ meters

Run Number	X- Impact	Y- Impact
1	9899.19	9899.19
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19	9899.19	9899.19

Table B6. Dynamic simulation results, Case II, Geometry II

$(\rho\ cep)_c = 14.7$ meters

Run Number	X - Impact	Y- Impact
1	9897.75	9901.25
2	9872.85	9888.37
3	9897.13	9900.95
4	9900.47	9928.21
5	9878.70	9893.80
6	9909.37	9928.70
7	9925.24	9911.73
8	9899.12	9908.16
9	9916.19	9883.02
10	9911.81	9897.35
11	9910.31	9901.49
12	9902.41	9905.92
13	9886.09	9893.88
14	9890.30	9883.37
15	9898.23	9896.87
16	9893.92	9892.00
17	9890.62	9891.01
18	9904.41	9910.73
19	9876.92	9884.41

Table B7. Dynamic simulation results, Case III, Geometry II

$(\rho \ \mathrm{cep})_c = 13.3$ meters

Run Number	X - Impact	Y - Impact
1	9917.77	9910.95
2	9891.85	9900.03
3	9895.44	9899.69
4	9904.86	9906.10
5	9901.91	9904.92
6	9891.11	9902.10
7	9899.64	9905.57
8	9924.21	9916.19
9	9880.36	9881.50
10	9903.22	9916.23
11	9877.79	9878.58
12	9905.67	9901.39
13	9905.41	9897.70
14	9908.51	9925.64
15	9904.11	9906.29
16	9897.86	9901.45
17	9888.16	9876.50
18	9896.77	9886.50
19	9902.83	9903.88

Table B8. Dynamic simulation results, Case IV, Geometry II

$(\rho \text{ cep})_c = 19.6$ meters

Run Number	X - Impact	Y - Impact
1	9916.57	9913.06
2	9865.80	9889.35
3	9893.56	9901.67
4	9906.35	9935.33
5	9881.64	9899.64
6	9901.45	9931.75
7	9925.94	9918.28
8	9924.32	9925.39
9	9897.49	9865.53
10	9916.03	9914.48
11	9889.00	9881.01
12	9909.07	9908.31
13	9892.53	9892.54
14	9899.68	9909.89
15	9903.30	9904.16
16	9892.76	9894.43
17	9879.81	9868.55
18	9902.18	9898.17
19	9880.73	9889.26

DISTRIBUTION LIST

Commander
US Army Armament Research and Development Command
ATTN: DRDAR-CG, MG B.L. Lewis
DRDAR-LC, COL P.B. Kenyon
DRDAR-LCN, COL G.M. Lubold
DRDAR-LCN-F, J. Masly (2)
DRDAR-LCU, A. Moss
DRDAR-LCF, F. Saxe
DRDAR-TSS (5)
Dover, NJ 07801

Commander
US Army Materiel Development and Readiness Command
ATTN: DRCPM-NUC, COL J. Sloan, Jr.
Dover, NJ 07801

Commander
US Army Materiel Development and Readiness Command
ATTN: DRCLDC, T. Shirata
5001 Eisenhower Ave
Alexandria, VA 22333

Deputy Chief of Staff for Research, Development
and Acquisition
ATTN: DAMA-CSM-N, LTC Ogden
DAMA-CSM-N, MAJ Brook
Washington, DC 20310

Commander
US Army Nuclear Chemical Agency
ATTN: MONA-MS, Bldg 2073
7500 Backlick Road
Springfield, VA 22150

Commander
US Army Research Office
ATTN: DRXRO-PR, A. J. Van Hall
P.O. Box 12211
Research Triangle Park, NC 27709

Polytechnic Institute of Brooklyn
ATTN: Dr. R. Haddad (2)
333 Jay Street
Brooklyn, NY 11201

Commander
Defense Documentation Center (12)
Cameron Station
Alexandria, VA 22314

US Army Armament Materiel Readiness Command
ATTN: DRSAR-LEP-L
Rock Island, IL 61299

Director
US Army TRADOC Systems Analysis Activity
ATTN: ATAA-SL (Technical Library)
White Sands Missile Range, NM 88002

Weapon System Concept Team/CSL
ATTN: DRDAR-ACW
Aberdeen Proving Ground, MD 21010

Technical Library
ATTN: DRDAR-CLJ-L
Aberdeen Proving Ground, MD 21005

Technical Library
ATTN: DRDAR-TSB-S
Aberdeen Proving Ground, MD 21010

Technical Library
ATTN: DRDAR-LCB-TL
Benet Weapons Laboratory
Watervliet, NY 12189